JOURNAL
OF THE
FRANKLIN INSTITUTE
OF THE STATE OF PENNSYLVANIA
FOR THE PROMOTION OF THE MECHANIC ARTS

VOL. CLXII, No. 4 81ST YEAR OCTOBER, 1906

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ELECTRICAL SECTION.

(Stated Meeting, held Thursday, March 22d, 1906.)

The Mercury Arc: It's Properties and Technical Applications.

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SECTION I.—*Structure of the Mercury Arc.*

We understand in what follows by "Mercury Arc" an arc through mercury vapors in a perfectly exhausted space.*

The *structure* of this arc varies with the conditions, such as temperature, pressure of the mercury vapor, etc. In general, we can distinguish (1) a *homogeneous* part, beginning at the

*The arc discharge through mercury vapor in an atmosphere of foreign gas is accordingly excluded from our consideration.

anode and ending at a certain distance from the cathode. This part is similar to the positive column of the ordinary Geissler discharge. We will designate it, therefore, by the name Positive Column of the Mercury Arc. (2) In the neighborhood of the cathode and following the positive column a *relatively dark space*, similar to the cathode dark space of the Geissler discharge. (3) Finally, at the cathode itself a bright patch which we will call the *cathode spot*. This spot is usually in irregular motion on the surface of the cathode.

The most important deviations from this normal structure can be summarized as follows:

(a) The cathode dark space is the more developed the larger the diameter of the tube at a given current, or, in other words, the smaller the current density. In narrow tubes at high current densities the cathode dark space disappears completely. (b) If the mercury vapor pressure in the arc space gets above a certain value the positive column no more fills the entire section of the tube, but rather concentrates itself in the middle of the tube, being surrounded on all sides by a space of relatively weak luminosity and very small conductivity.

If the mercury arc is to present its normal appearance, such as described at the beginning, the mercury vapor pressure must be kept below a certain maximum value. This can be achieved either by regulating the dissipation of heat from the surface of the arc itself, or else by providing a chamber lying outside of the path of the arc, in which the mercury vapor can condense. This part of the tube will be designated by the name "condensing chamber."

In the description of the different parts of the arc that follows, we will assume that we have to deal with an arc of normal structure.

1. *Anode.*

The anode of the mercury arc can consist of any conducting material of sufficiently high melting point which does not combine with mercury. In practice, only three materials are in use, mercury itself, graphite and iron (or nickel).

When mercury is used the distribution of current at the surface is, under normal conditions, uniform all over. Only when the mercury vapor pressure goes up above the permissible limit

does the distribution become more or less localized, the arc leaving the surface mostly at the side nearest to the cathode. The heat evolved at the anode is used up in volatilizing the mercury. This increases the pressure of mercury vapor in the tube and larger condensing chambers are necessary to keep the pressure down to its normal value.

If graphite or iron are used as anodes, the arc usually leaves the anodes at those parts which are nearest to the cathode. The heat evolved at the anode serves to increase its temperature and the resulting temperature is the result of an equilibrium between two factors, the production of heat at the anode and the conduction of heat by the mercury vapor surrounding the anodes. It increases with the current and its upper limit is only determined by the melting point or boiling point of the material. The heat evolved at the anode is due to the existence of a certain potential drop at the surface of contact between the anode and the arc. The magnitude of this "anode polarization" depends on the material used, its temperature, and is therefore not a characteristic quantity.

2. *Positive Column of the Arc.*

The positive column presents in the normal arc a uniform appearance, with no striations whatever. Only in the case of very small current and seemingly *only in the presence of foreign gases* do striations appear. This case is interesting, as in contradistinction to the Geissler discharge, the striations appear here at low voltage. The potential drop in the positive column has a certain value per unit length and is the smaller the larger the diameter of the tube. A *simple* relation between the diameter and the drop does not exist. In a tube of 1.8 cm. diameter the potential drop per cm. is equal to about 0.72 volt. The potential drop depends, of course, on the pressure of the mercury vapor in the tube. The above given value refers to a good vacuum and to the case when the pressure of mercury vapor is kept low by a condensing chamber, but no exterior cooling means are used. The drop per unit length in the positive column, being thus variable, is not a characteristic quantity of the arc.

SECTION II.—*Properties of the Cathode.*

The properties of the cathode are of such importance that a special chapter must be devoted to them. The processes going

on at the surface and in the neighborhood of the cathode are essential both for the maintenance and for the initial starting of the arc.

(a) The following experiments will show the role of the cathode in the *starting* of the arc:

The tube *ABC* (Fig. 1) has two cups, *B* and *C*, filled with mercury, and a graphite electrode *A*. *B* and *C* are connected to one source of direct current, *B* and *A* to another; let us imagine that the connections are made at first in such a way that *B* is the common *negative* pole of the two sources. If the electrodes *B* and *C* are brought into contact and separated the arc *BC* starts, *B* being its cathode. We find then that on closing the switch of the circuit of the other generator, G_1, the arc *AB* starts instantaneously.

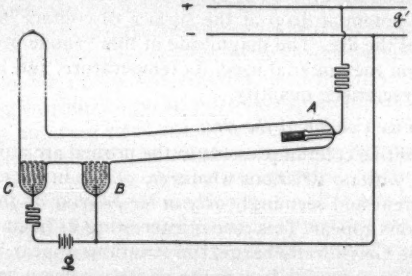


Fig. 1.

If the connections are changed in such a way that *B* is the common *positive* pole of the two sources and the arc *BC* started as before, the arc *AB* does not start on closing the switch. This *dissymmetrical* behavior shows how entirely different the electrode *B* behaves when it is cathode and when it is anode of an arc.

The experiment succeeds also when the graphite anode *A* is replaced by a mercury electrode. In this case, however, the arc *AB* may sometimes start up, even when *B* is anode, for the reason that the mercury cathode *A* can be rendered active by other causes than by an already existing arc.

Since ordinary mercury vapor is a non-conductor and since the experiment described shows that the excitation of the ca-

thode by means of the auxiliary arc *BC* is necessary for the starting of the arc *AB*, we are forced to the conclusion that *the production of the conducting vapor takes place, at least in the very first stages of the development of the arc, at the surface of the negative electrode.*

In the ordinary process of starting an arc by contact it is impossible to separate the function of the cathode from that of the anode. The experiment described above represents for an arc in vacuum such a separation and shows the complete difference between the behavior of the cathode and that of the anode, a difference which is of fundamental importance for any theory of the arc discharge.

The experiment succeeds well only when the vacuum is very good, *i. e.*, in absence of foreign gases, and also in absence of too large an excess of ordinary mercury vapor. In other words, the experiment succeeds well at ordinary temperature in a perfectly exhausted tube, the anode and the walls of the tube having been previously freed from all gases absorbed on their surface. If the vacuum is not perfect or if the tube is hot, so that too much mercury vapor is present, the starting of the arc *AB* is not instantaneous and one can see the conducting ("ionized") vapor spreading slowly from the cathode *B*. When this ionized vapor reaches the anode *A* the arc *AB* usually starts, although if the vacuum is too poor the starting may not take place.

(b) *Role of the Cathode in the Maintenance of the Arc.*

In the chapter on the stability of the mercury arc we will see that under given conditions there exists a minimum value of current at which the arc is stable and below which it goes out. Under ordinary conditions this minimum value lies at about three amperes. Experiments have shown that the instability of the arc below the minimum value is due, to a large extent, to the *wandering* of the cathode spot on the surface of the mercury cathode.

The fact that there exists a bright patch on the cathode and that this patch constantly and irregularly wanders about on the surface of the mercury has already been mentioned above. The cause of the wandering has not yet been ascertained.

This wandering can be avoided in two different ways. The first way consists in the use of a platinum or iron wire protruding above the surface of the mercury. If the current is not

large, say not above five amperes, the cathode spot fixes itself around the wire at the point where the wire crosses the mercury surface. The second way consists in the use of a narrow tube of refractory material, such as silica or porcelain, the cathode spot being produced by means to be described later (Section 3) on the mercury surface inside this narrow tube. In this case the spot remains always inside of that tube.

Now, if the cathode spot is fixed by either of these two methods, the value of the *minimum current is considerably lowered.* In the case of a narrow silica tube surrounding the cathode spot, the value of the lower limit is about 1½ amperes; in the case of the platinum wire about .9 ampere. This result, viz., that the wandering of the cathode spot on the mercury surface causes the arc to go out, is again a strong argument in favor of the theory that the production of the current carrying material takes place in the cathode spot, every disturbance of that process, such as is caused by the wandering of the cathode spot, being able to stop that process altogether.

(c) *Polarization of the Cathode.*

At the surface of the cathode there is a potential drop equal to about five volts. This quantity is independent of the current, mercury vapor pressure, etc. The polarization voltage at the anode, as well as the drop in the arc itself, were shown to be variable quantities.

The cathode spot is the larger the larger the current. It is quite possible that when the current is such that the cathode spot covers the whole surface of the cathode, further increase of the current would change the value of the cathode potential drop.

(d) *Disintegration of the Cathode.*

It is possible to realize mercury arcs, that is, arcs through mercury vapors in an exhausted space, with a cathode consisting of any conducting material. If in the tube *AB* (Fig. 2) the graphite electrode *A* is connected to the negative pole of a direct current circuit and *B* to the positive pole, and the electrodes brought into contact by shaking, an arc starts with the graphite as cathode. These solid cathodes, as I will call them, for the sake of brevity, show the same behavior with respect to the starting of the arc as an ordinary mercury cathode. Thus the fundamental experiment described in the beginning of this Sec-

tion can be repeated with a solid cathode. [*B* (Fig. 1) is made of graphite, iron or any other conducting material.] Care, of course, must be taken to free that electrode from absorbed gases before trying the experiment. With these solid cathodes another phenomenon, however, is observed, viz., the *mechanical disintegration of the material of the cathode.* The cathode spot exists also on the solid cathodes. A well defined and sharply outlined red hot spot wanders irregularly on that surface and at the same time small particles of the material are being incessantly projected from that spot, collecting on the walls of the tube. *This disintegration of the cathode represents another essential difference between*

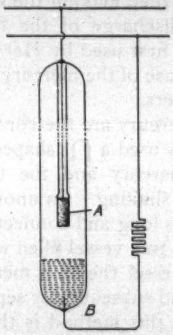


Fig. 2.

the anode and the cathode of the arc in metallic vapors in an exhausted space. In the case of one material, viz., of charcoal, one succeeds in obtaining on the surface of the electrode *sharply outlined, fine grooves which show the path followed by the cathode spot.* Measurements of the dimensions of these grooves, their width and depth at different currents under different conditions, might lead to interesting conclusions. In the case of all other materials every particle disintegrated electrically causes, by loosening the structure, other particles to separate mechanically in such a way that no trace of the cathode spot is left on the surface. The material produced by the disintegration of the cathode differs usually in its physical properties from the original material of the cathode. If graphite, for instance, is used, the

disintegrated material has no cohesive properties, is a very poor conductor and leaves no trace on paper. The chemical properties ,however, remain the same.

SECTION III.—*Starting of the Mercury Arc.*

The methods usually used to start an arc can be described as the "*contact*" *method* and the "high potential" method.

In the first method, which is used in the carbon arc, in flame arcs, etc., the arc is started by bringing the two electrodes into contact and separating them.

The second method consists in sending for a short time a discharge from a high potential source through the space between the two electrodes and then making the low voltage source follow the path of the discharge of the high potential. (This method was, I believe, first used by Herschel.) Both methods have been used in the case of the mercury arc by Arons, Cooper Hewitt, myself and others.

In the case of the mercury arc the contact method has taken different forms. Arons used a ∩ shaped tube, the tube being partially filled with mercury and the two mercury surfaces brought in contact by shaking. In another arrangement one of the legs of the tube is long and connected at its lower end by means of a rubber tube to a vessel filled with mercury. By lowering or raising this vessel the two mercury surfaces can be brought into contact and subsequently separated.

One form I gave to this method is that of a straight horizontal tube, with two cups filled with mercury. By inclining the tube a stream of mercury is caused to flow from one electrode to the other and this establishes contact for a short interval of time. This movement of the tube can be produced automatically by a current flowing through magnets in shunt with the tube.

A similar arrangement has also been used by Cooper Hewitt, the shaking of the tube being done by hand. It is obvious that a number of other ways can be found, such as heating the mercury and causing it to expand, etc., all for the purpose of bringing the two mercury surfaces in contact.

The high potential method has been used by Arons and then afterwards by Peter Cooper Hewitt.

A "kicking" coil and a quick break switch are placed in shunt

to the mercury tube. On opening the quick break switch the high potential created at the end of the reactance discharges through the space between the electrodes in the mercury tube, whereupon the low voltage follows in the path of the discharge and establishes an arc.

The Sidebranch Method—Excitation of the Cathode.

The new method for starting the mercury arc that I proposed is founded on the cathode properties which have been described in the previous chapter. We have seen that if the negative pole

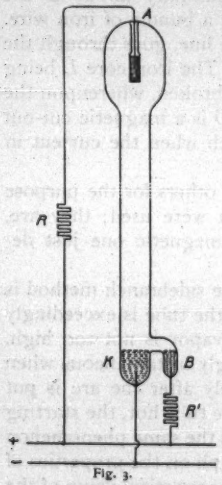


Fig. 3.

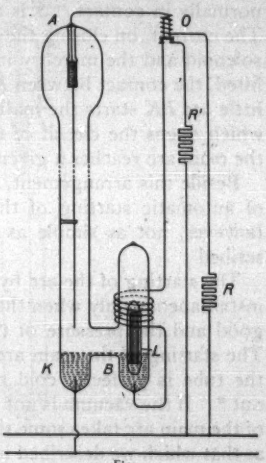


Fig. 4.

which is to be the cathode of the arc is excited by an auxiliary arc and the vacuum in the tube is good, an arc will instantly establish itself between this cathode and any anode.

The tube represented in Fig. 3 shows one of the ways in which this property can be used for the purpose of starting an arc. K represents a mercury surface connected to the negative pole of the source of direct current. A represents the electrode which is to be the anode of the arc. B is also connected to the positive pole of the source of direct current. R and R_1 are two resist-

ances. If by slight shaking of the tube the electrodes *K* and *B* are brought into contact and separated, a short arc is formed which excites the cathode *K* and causes the starting of the main arc, *AK*. The auxiliary arc, *KB*, can then be extinguished by opening a switch in the line of the auxiliary anode *B*. The side tube *KB* is called "the sidebranch," *B* the auxiliary or "starting" anode, and the method of starting is called the "*sidebranch method.*" The auxiliary arc, *KB*, instead of being started by shaking, can, of course, be started automatically in many different ways; one of the first used is shown in Fig. 4. The mercury surfaces of the cathode *K* and the auxiliary anode *B* are normally in contact. *S* is a solenoid, *L* a bundle of iron wire. The current, on closing the switch in the line, goes through the solenoid and the mercury in *B* and *K*. The iron core *L* being lifted, the contact between *KB* and *K* is broken, whereupon the little arc *BK* starts the main arc *KA*. *O* is a magnetic cut-out which opens the circuit of the sidebranch when the current in the main arc reaches a given value.

Beside this arrangement, a number of others for the purpose of automatic starting of the sidebranch were used; they are, however, not as simple as the electro magnetic one just described.

The starting of the arc by means of the sidebranch method is instantaneous only when the vacuum of the tube is exceedingly good and the pressure of the mercury vapor is not too high. The starting of the main arc is accordingly instantaneous when the tube is perfectly cold or immediately after the arc is put out.* If the vacuum is not perfect or the tube hot, the starting of the main arc takes some time. This is the same phenomenon as that which we described in the paragraph on the properties of the cathode and would suffice to make the practical value of the sidebranch method of starting rather small. The difficulty has, however, been overcome by suspending from the anode a carbon filament of high resistance and of such a length that its lower end is but a few inches away from the mercury cathode. For the starting of the arc this means a shortening of the distance between the anode and the cathode. After the arc is started a very small current only flows through the carbon filament, the

*The ionation in the path of the arc persisting for a short while.

arc having a much lower resistance. The filament is seen in Fig. 4.

Out of the use of this carbon filament as a device for the facilitating of the starting of the mercury arc, another method of starting developed. The carbon filament, instead of reaching within a certain distance from the cathode, actually touches the latter, so that, on closing the switch, the current finds a way from the anode to the cathode, through the carbon filament.

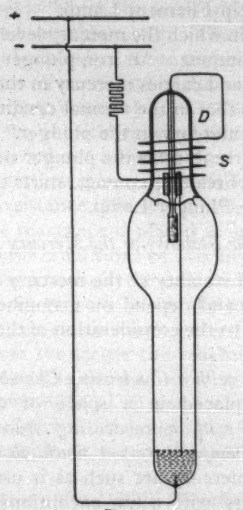


Fig. 5.

This current is caused by energizing a solenoid, to separate the filament from the mercury cathode, either by lifting the filament or by lowering the level of the mercury. The little arc thus formed between the end of the filament and the mercury cathode instantaneously develops into the main arc between the mercury cathode and the anode. An arrangement in which the carbon filament is lifted is shown in the next sketch (Fig. 5.)

The carbon filament is attached to an iron cylinder which forms a sliding contact with the rod *D*, which rod is directly connected to the leading-in platinum wire. The current at first

flows through the solenoid S, the leading-in platinum wire, carbon filament, mercury cathode, back to the source. The energized solenoid in pulling up the iron cylinder to which the carbon filament is attached starts the arc. In some of the arrangements the upper part of the rod D is coated with an insulating layer of glass, so that when the sliding cylinder is pulled up, the current flow through the carbon filament completely ceases and the carbon filament is cut out of circuit. This lamp is given the name of the "Lift-Up Filament Lamp."

An arrangement in which the mercury level is lowered was designed by C. P. Steinmetz. An iron plunger, the upper part of which is drilled out and carries mercury in the hole, floats in the mercury cathode so that in the normal condition the filament is in contact with the mercury in the plunger. A solenoid, when energized by the current, pulls the plunger under the surface of the mercury and by breaking contact, starts the arc. This type of lamp is called the Plunger Lamp.

SECTION IV.—*The Stability of the Mercury Arc.*

The conditions of stability of the mercury arc are of a rather complicated nature and depend on a number of factors. We shall limit ourselves to the consideration of the two most important cases.

1st. *Mercury Arc with a Condensing Chamber.*—We shall first consider the arc placed in a space of ordinary temperature and *provided with a condensing space, certain parts of which remain at a temperature not much above the surrounding temperature.* The mercury arc such as is used for purposes of illumination, belongs, with a few exceptions, to this type.

In this case the potential across the arc at first diminishes as the current increases, until a certain point is reached above which the variations of potential and the current have the same sign. The potential drop across the lamp meant is not the one which is established immediately after the current is changed, but rather the one which corresponds to the equilibrium, the equilibrium being reached only after a certain time. Let A be the value of current which corresponds to the minimum value of the potential drop across the arc. Then it is obvious that for currents below the one corresponding to A the arc is in an unstable condition, since to

a slight diminution of current there corresponds an increase of voltage across the tube, which causes in its turn a diminution of current, the process going on until the voltage drop comes near to the impressed voltage and the arc goes out.

For currents above the value A the arc is in a stable condition (the current being, however, not too high, since then the condensing chamber is no more at a sufficiently low temperature.) These considerations show that there exists for a normal arc a minimum current below which the arc is unstable and goes out. The experiment confirms this result. That minimum value is usually in the neighborhood of three amperes. This explanation of the existence of a minimum current, although in all probability correct from a formal point of view, does not give us any insight into the physical cause of the phenomenon. This cause was partly pointed out in Section 2.

In all the considerations given above it was assumed that a certain regulating resistance is in series with the arc, but no reactance. If a large reactance is placed in series with the mercury arc it changes the conditions of stability altogether. This is similar to what was known in the case of the ordinary carbon arc. With a large reactance in series the minimum current at which a normal arc can run is much lower than without reactance and is the lower the larger the reactance. With a sufficiently large reactance it is easily possible to have an arc with a current of only a few tenths of an ampere. The action of the reactance, which consists in introducing an e. m. f. every time the current tries to diminish, is too obvious to require any discussion.

2d. *The Arc Without a Condensing Chamber.*—If the arc is not provided with a condensing chamber its stability depends a good deal on the conditions of radiation and heat conduction on the surface of the tube itself, the temperature rising until thermical equilibrium is reached between the energy input and the heat radiated from the surface of the tube. The temperature corresponding to this equilibrium and accordingly the pressure of mercury vapor in the tube being much higher than in the case of the arc with condensing chamber, the potential drop across the arc is considerably higher, and the curve connecting this potential drop with the current is also different. It is, however, possible to have an arc run stable under these conditions

by a proper choice of the impressed e. m. f., the resistance in series with the arc and the external temperature.

SECTION V.—*Arcs in Metallic Vapors Other than Mercury.*

The arc in the vapors of other metals which are sufficiently volatile, has in general the same properties as the arc in mercury vapors. The investigation included the following metals: Potassium, sodium, alloys of the two as well as with lithium, bismuth, lead, tin, zinc, cadmium and alloys of those metals which have a low melting point, such as Wood's metal, finally amalgams of all the above-named metals, etc. In most cases the arc was produced inside of a glass vessel, although in the case of the less volatile metals a silica vessel was often used, the silica vessel containing the metal and being suspended inside of a glass tube or bulb. In the case of the alkali metals and of the easily fusible alloys of the other metals, such as Wood's Alloy, etc., it is easily possible to produce in a well exhausted tube arcs of practically any desired length. Those arcs have essentially the same properties as the ordinary mercury arc. A cathode spot exists on the surface of the metal, whether this metal be liquid or solid. This cathode spot is wandering about the surface and all the experiments that have been described in the case of the mercury arc can be repeated here. The anode can be made of any material and consisted in the experiments mostly of a piece of graphite.

The spectrum emitted changes of course with the nature of the metal. The amount of light is usually small and the efficiency small. This is due to the small amount of material in the space, in consequence of the low vapor tension of these metals. If the exhaustion is made by means of a mercury pump the small amount of mercury vapor present in the space is sufficient to give to the arc immediately after starting the character of a mercury arc. As the material of the cathode volatilizes the mercury vapor spectrum is being replaced by the spectrum of the corresponding metal.

If amalgams are used the spectrum of the arc shows lines due to the mercury as well as to the metal dissolved in it. The proportions in which the radiations of the two metals are represented in the spectrum depends, of course, on the percentage of the metal dissolved in the mercury. It also depends on the

current. When dilute amalgams of alkali metals are used the lines due to sodium or potassium begin to appear only when the current reaches a certain value. The addition of the alkali metals or of the metals like calcium, strontium, link, etc., could be used for the purpose of improving the color of the light emitted by the mercury arc. (See Section Technical Applications.)

The drop of potential across the arc, as well as the single drops at the electrodes, are of the same order of magnitude whatever the metal used.

SECTION VI.—*Alternating Current Phenomena in the Mercury Arc.*

Alternating voltages of moderate value are incapable of maintaining an arc in mercury vapors in an exhausted space. The spark formed on separating the two electrodes dies out, no matter how large the current it carries.

This phenomenon is easily accounted for on the basis of the principles laid down in the Section on the cathode properties. An arc cannot exist without a constant source of conducting material at the negative electrode. If the production of conducting material ceases at the cathode, the arc is bound to go out, unless by some means the cathode surface is rendered active anew. In the case of an alternating voltage, however, the negative pole changes from one mercury surface to another. The emission of negative ions which is started by the initial separation of the electrodes dies out and with it the arc. The conditions change when the alternating voltage is high enough to render the cathode active at each alternation. This we will discuss later; we limit ourselves here to the case of an alternating voltage of moderate value.

In this case, one way of making a *current derived from an alternating source pass through mercury vapors is to keep one of the electrodes active by making it the cathode of an auxiliary direct current arc.* The arrangement is the same an on Fig. 1, with the difference that g^1 is an alternator.

CB is a direct current arc with *B* as cathode. *B* and *A* are connected to the terminals of a source of alternating voltage. The electrode *B* being constantly kept active by the direct current, the half wave of the alternating voltage, for which *B*

is the negative pole, can send a current through the space between *B* and *A*. The half wave of opposite sign cannot pass. Accordingly, we get in the circuit of *BA* a pulsating unidirectional current. The interest of this arrangement is obvious, as it gives us a way of deriving unidirectional, although pulsating current from an alternating source.

By providing two auxiliary direct current sources and connecting the alternating current source to the two cathodes of the direct current arcs, an *alternating* current can be made to pass between those two cathodes. The discussion of this case,

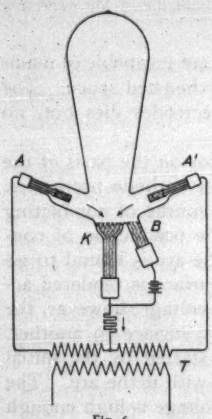


Fig. 6.

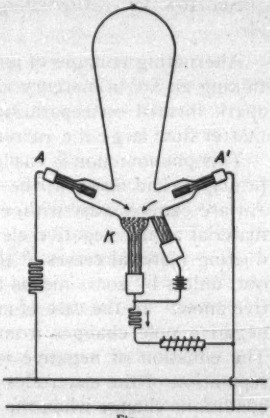


Fig. 7.

in spite of its interest, I must omit, in order not to make this article too voluminous.

Returning to the first arrangement, in which only one direct current source is used, we see that a pulsating current is derived, only one half wave being utilized. To utilize both half waves and superimpose them in the same direction in the same circuit, an arrangement can be used which is represented in Fig. 6. There are two anodes in the tube to which two terminals of the secondary of a transformer are connected. The middle point of the secondary is connected to the cathode. An auxiliary direct current source, *BK*, serves to excite the

cathode. As is easily seen, for each direction of the alternating voltage one half of the secondary sends a current through the tube in the right direction—that is, in such a direction that K is cathode. The current derived in the wire connecting the cathode to the neutral point of the transformer consists now of an uninterrupted series of pulsations. It pesses through zero every half period and the auxiliary direct current source has only the function of keeping the cathode active during those intervals of time when the alternating current is zero or in the neighborhood of it.*

The use of a direct current for the excitation of the cathode can be dispensed with *if the property of reactances* of accumulating energy when the current flowing in them increases and discharging that energy when the current begins to diminish, is *made use of*. A rectifier constructed on this principle and in which only one half wave is rectified, is shown in the next sketch (Fig. 7.)

The electrodes A and A^1 are connected to the two poles of the alternating current source. Between A^1 and the middle electrode K, a reactance coil is placed. If by any means K is made for an instant cathode, either by an auxiliary direct current or by preliminary contact of K with A, the following processes go on: The half wave for which A is anode passes in the direction from A to K, then through the reactance and when this current begins to diminish, the reactance discharges mostly through the space A^1K in the direction shown by the arrow. If this discharge takes a sufficiently long time, the cathode is kept going during that half period, when otherwise there would be no current.

To get both half waves rectified by the use of reactances, the arrangement shown above must simply be made symmetrical by the use of two reactance coils, in the way shown in the next sketch (Fig. 8.) It will be seen that both half waves, as well as the discharges of the reactance coils, have the same surface, K, for cathode, and that in the wire connecting the cathode to the point between the two reactance coils a continuous direct current is flowing. The load, which can con-

*Of course the Graetz connection could be used; it is, however, less advantageous than those described.

sist of a resistance or storage battery, etc., has therefore to be placed in this line.

It will readily be seen that the result achieved in the last arrangement by the use of two reactance coils can also be achieved in the arrangement described above (Fig. 6), where the neutral wire of a transformer is used by simply introducing a sufficiently large auxiliary reactance into the neutral wire between the middle point of the transformer and the cathode.

SECTION VII.—*Arcing.*

The two electrodes, A and A^1, in the rectifier described last, the anodes of the rectified currents, are, when the arcs run,

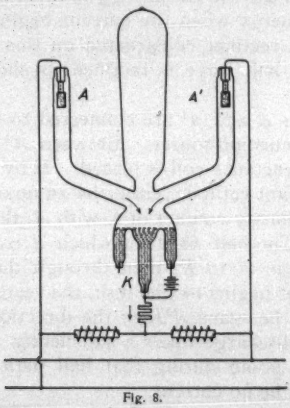


Fig. 8.

surrounded by highly conducting vapor and it is at first glance surprising to find that no arc develops between them. The absence of an arc discharge directly between the two anodes is easily accounted for on the principles expounded above by the absence of a cathodic center on either one of the two anodes. If such a cathodic center is for one reason or another formed on one of the two anodes, an arc discharge between the two anodes takes place, and this phenomenon was termed "arcing of the rectifier." In absence of such a cathodic center a very small "leakage current" probably exists between the two elec-

trodes (since one always finds currents of the order of magnitude of 1 milliampere between two exploring electrodes placed in the mercury arc and to which an e. m. f. of moderate value is applied.)

The conditions under which this leakage current develops into an arc discharge—in other words, the conditions under which in presence of conducting vapor, a cathodic center is produced on a negatively charged surface, are of considerable theoretical interest. The following experiments are of interest in this connection:

Let us return to the experiment by means of which we illustrated the importance of the cathode in the starting of the mercury arc. The tube is the same as that represented on Fig. 1 and the connections are also the same as there. The only difference is that the anode A is made of *mercury* instead of graphite. The phenomena described in the corresponding paragraph remain the same, whatever the material of the anode. If B is made cathode by starting the arc BC, the arc AB starts up instantaneously (provided there is a good vacuum in the tube.) If the electrode B is the common anode the arc AB does not usually start. However, when the ionized vapor which diffuses from the arc CB fills the space between the electrodes B and A, a small leakage current between A and B takes place. If A is graphite or iron this state continues indefinitely. If A is mercury the arc may eventually start between B and A, A becoming the cathode of the new arc. The experiment can be given even a more effective form by placing the cup A between the electrodes B and C. In that case, in spite of the presence of the highly conducting vapor of the arc C, a small leakage current only exists between A and B. It is, however, more difficult to maintain this condition and the arc starts rather readily.

In these two experiments with direct current arcs we are therefore confronted with the same problem of the formation of a cathodic center on the surface of a negatively charged body. The experimental results obtained in the study of this question, the practical importance of which is obvious from the connection with the arcing of the rectifier, can be summarized as follows:

(a) The ease with which a cathodic ionization center forms

on the surface of a negatively charged electrode varies with the material of which that electrode is made.

The ease of formation seems to be connected with the boiling point of the material, and is, therefore, unless certain necessary precautions are taken, greater in case of mercury than in the case of solid electrodes.

In the rectification of very high potentials, such as given by an ordinary induction coil or high potential transformer (say 30,000 to 40,000 volts) and very often also in the rectification of voltages somewhat below (around 10,000) the influence of the material on the ease of the formation of a cathodic center is shown in a very striking way. The graphite anodes are usually fastened by means of leading-in platinum wires, which are insulated either by a coat of glass or by glass tubes surrounding them. Experiments show that at the high voltages mentioned above a cathodic center is more *liable to form on the glass which surrounds the platinum wire than on the graphite.* A bright cathode spot appears on the glass, causing it to melt and volatilize. The gases evolved spoil the vacuum, and the cracking of the seal often destroys the tube. The fact that on glass and similar materials the cathode spot forms more readily than on graphite or iron is again probably connected with the fact that glass can give off vapors of sodium and similar metals.

(b) *The Influence of the Potential.*—It is natural that the formation of the cathode center takes place the more readily the higher the potential applied. In fact, one of the older methods of starting a mercury arc by the "kick' of a large inductance is based on the formation of a cathode center under the influence of high potential.

In the case of the mercury arc rectifier the danger of arcing between the two anodes increases as the voltage applied to the anodes increases. With graphite anodes, if necessary precautions are taken, the upper limit of potential at which arcing takes place has not yet been determined.

The formation of a cathodic center on a negatively charged mercury surface under the influence of high potential can be shown by the following experiments:

(1) Let *AB* (Fig. 2 only with reversed connections) represent a tube in which *B* is a mercury surface connected to a

negative pole of a source of undirectional low voltage and A is a graphite anode connected to the positive pole of the same source. If the distance between A and B is not too large (in some of the experiments it was, however, as large as 8 to 10 inches) mere shaking of the tube is apt to start the arc between A and B. It is obvious that the mechanical shaking can act only by producing a static charge of high potential on the surface of the mercury.

The next experiment seems to show that a considerable factor is the electric field intensity near the cathode.

(2) A tube AB has two mercury electrodes. One is of a very small surface, the other of a very large. On connecting these two electrodes to the secondary of a high potential transformer, cathode spots appear in the form of sharp, brilliant points only on the small surface, provided the current in the tube is kept low. This is explained by taking into account the different shape of the mercury surfaces constituting the two electrodes. The radius of curvature being much smaller in the case of the small electrode and accordingly the field intensity higher, the negative particles are propelled with greater force into the space and a cathode center forms more readily. If a direct current ammeter is placed in the circuit of the tube its deflection shows that rectification takes place. The direction in which the current predominates is, however, not necessarily the one for which the small electrode is cathode. At very small currents the current of opposite direction usually predominates, showing that the negative current, which leaves the large surface B in form of a *homogeneous* discharge, equally distributed over the whole surface, is larger than the negative current, which leaves the small surface in localized cathode points. As the current is increased the two opposite currents become equal, and when the cathode points on the small electrode grow sufficiently large, the negative current starting from them begins to predominate. If cathode spots form, as they often do, on the large surface B, they usually form in the neighborhood of the glass, at the place where the curvature of the mercury surface is smallest and the electric force perpendicularly to the surface accordingly the highest.

(c) *The Influence of the Position of the Anodes with Respect to the Cathode.*

We come here to a phenomenon which is surprising and the cause of which is not yet certain. The ease with which the cathodic center forms on one of the anodes of a high voltage rectifier depends on the relative position of those anodes with respect to the cathode. If the anodes are placed directly above the cathode arcing takes place more readily than if the anodes are placed at a certain angle to the perpendicular erected on the mercury surface and the danger of arcing is the smaller the larger that angle. If of the two anodes one is placed perpendicularly above the mercury cathode and the other either at a certain angle or even below the mercury level, the arcing, if it does take place, invariably has its cathodic point on the anode which is directly above the cathode. It seems as though the ionized vapor that usually shoots out from the surface of the cathode in a perpendicular direction (and is probably of an origin similar to the cathode rays) has some peculiar effect on the surface of the anode which facilitates the production of a cathodic center of ionization.

Section VIII.—Technical Applications.

I. *The Arc as a Source of Light.*

The luminous efficiency of the mercury arc in any of the forms described in Section III is quite high. Measured with a flicker photometer, which is the only one allowing comparison of lights of different color, this efficiency varies under different conditions between say .25 to 1 watt per candle, the watts meaning the consumption of energy in the arc itself. Under ordinary circumstances about 20% of the watt consumption in the arc is wasted in the ballast resistance (except in series lighting where no resistance is necessary) and some part of the light is also absorbed in the globe by which the arc itself must usually be surrounded. The physiological effects of the light on the human eye and the distribution of light being of different nature than in most other sources of artificial light, the above given numbers are of considerably less practical value than actual experiments made for instance with the luminometer—that is, an apparatus by means of which the distinctness of objects at a certain distance from the source can be ap-

proximately determined. These experiments show also that the mercury arc is a highly efficient source of light.

The life of the mercury arc lamp in one of the shapes described in Section III is very considerable, in some cases amounting to 3000 hours and more. In the course of time the glass of the tube in which the arc is enclosed blackens somewhat (in consequence of a chemical change in the glass) and in lamps with a carbon filament usually some blackening takes place, due to a deposit of carbon on the walls. This blackening causes a diminution of efficiency in time which amounts to about 20% at the end of the life.

The lamp needs no attendance, as there are no electrodes to replace.

Other advantages of the lamp are the fact that relatively small units can be made (the units now made consuming 160 watts) and the diffused distribution of light in contradistinction to the concentrated sources of light represented by other arcs.

All these advantages would certainly cause this lamp to be an important factor if it were not for the nature of the light emitted, which is practically devoid of red rays. In spite of this, the lamp is being used and will probably be used more and more extensively for purposes where this absence of red rays and the corresponding discoloration of objects is of little importance. In street lighting, the lighting of parks and suburbs, as well as of factories, drafting rooms and similar places, the lamp seems to be very suitable. The mercury arc lamp is essentially a direct current lamp. An alternating current lamp was also constructed and used, built on the same principle as a mercury arc rectifier, the starting device being similar to that used in the case of the direct current arc. The construction and connections are, however, somewhat more complicated.

The methods attempted for improving the quality of the light were as follows:

(a) *The use of ordinary incandescent lamps in series with the mercury arc.* The General Electric Company has developed the so-called Orthochrome Mercury Arc Lamp, in which a number of incandescent lamps in multiple are placed in series with the mercury arc, the incandescent lamps burning at a normal efficiency. The whole is enclosed in a Holophane globe,

which serves the purpose of blending the two lights of different colors. This system has, of course, a lower efficiency than the mercury arc alone and also leads to somewhat larger units.

(b) *The use of amalgams of the alkali metals and of the metals of the alkali earths.*—In Section V we saw that by adding metals like potassium, sodium, lithium, calcium, etc., to the mercury, the spectrum of the arc can be changed. The practical application for the purpose of improving the color of the mercury arc meets, however, with considerable difficulties and disadvantages of which I mention the attack on the glass by the alkali metals, the lowering of the efficiency, etc.

(c) *Use of fluorescent bodies which have the property of transforming the violet and green rays into those nearer the red end of the spectrum.*—Unfortunately none of the substances known possess this property in a degree sufficient for practical purposes; also this transformation is very wasteful.

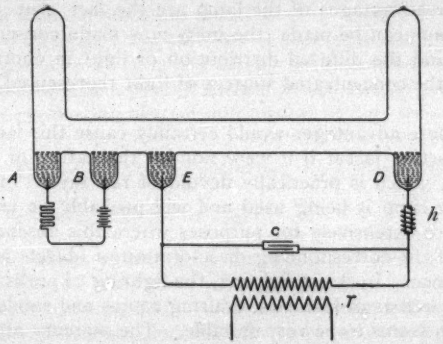


Fig. 9.

(d) *Change of the nature of the discharge through the mercury vapors.*—The spectrum of the light emitted by the discharge through vapors or gases depends on the nature of the discharge. Work in this direction for the purpose of improving the color of the mercury arc has given promising results. One of the experiments, showing the essentials of the phenomenon, is illustrated in the sketch (Fig. 9.)

T is a transformer of not too small a capacity, C condensers,

h a small inductance; *AB* is a direct current arc which supplies ionized vapor, this ionized vapor filling the space between the two other electrodes, *E* and *D*. Under proper conditions the discharge of the condenser between the electrodes *E* and *D* has a spectrum rich in red rays, the arc *ED* giving a brilliant white light.

II. *Use of the Mercury Arc Rectifier.*

(a) *The constant potential rectifier.*—The mercury arc rectifier represents so far the best solution of the problem of transformation of alternating to direct current, so long as the power to be transformed is not very large. The power depending on the two factors, the voltage and the current, we will consider the two separately.

The current that can be transformed by means of the mercury arc rectifier has theoretically no limit. Practically, however, one is limited by the difficulties of introduction of large currents into an exhausted glass vessel and more yet by the difficulties in dissipating the heat disengaged in the rectifier itself. Both difficulties may be overcome by a change of the material, of which the rectifier is now being made (viz., glass.)

The voltage which can be rectified by means of the mercury arc rectifier is exceedingly high. In connection with this I must refer to the section in which arcing is discussed, and from it will be seen that the voltage rectified can be the higher, the smaller the current.

The magnitude of voltage that can be rectified makes the mercury arc rectifier infinitely superior to the electrolytic rectifier.

The efficiency of the mercury arc rectifier depends on the voltage to be rectified and is the higher the higher that voltage. This is due to the fact that the voltage consumed by the rectifier itself is a constant quantity, independent of the current. In the ordinary constant potential rectifiers that loss amounts to about 17 volts. The efficiency of the mercury arc rectifier for ordinary voltages of 100 to 200 volts is therefore much higher than that of electrolytic rectifiers. The power factor can also, by a proper choice of the reactances, be made as high or higher than 90%.

The high efficiency and simplicity of the mercury arc rectifier cause its use to spread every day. It is used especially for charging storage batteries in connection with automobile and telephone work, also in a number of other cases, such as driving small direct current motors from an A. C. source, feeding induction coils in connection with an interrupter, etc.

(b) *"Constant Current" Rectifier.*

The constant current rectifier differs from the constant potential only in the fact that a constant current transformer is used instead of a constant potential transformer. The use of the constant current rectifier in connection with direct current arc lamps, especially the Magnetite Lamp, also developed in the Research Laboratory of the G. E. Co., is of growing importance. A number of installations have been made in which 25 to 75 Magnetite Lamps, each consuming 80 to 100 volts, are used as a load in the direct current side of a constant current arc rectifier, to the alternating current side of which about 15000 to 20000 volt are applied. The description of this system of lighting alone could be a subject for a separate paper, so I cannot go into detail at this place.

(c) *The High Frequency Rectifier.*

The mercury arc rectifier is capable of rectifying alternating currents of frequency as high as that given by a condenser discharge—that is, of the order of magnitude of 10^6 to 10^{10} oscillations per second. So far, no limit could be found, although it is practically impossible to prove that the rectification is complete. This property can be used in connection with wireless telegraphy, the mercury arc rectifier serving to rectify the oscillations received in the antennae, and a sensitive direct current galvanometer used in connection. The arrangement of the receiving station is represented in the sketch (Fig. 10.)

T is the transformer transforming the oscillations to higher potential and provided with a neutral wire. The connections to the rectifier are the same as those described in Section VII so that both half waves are rectified. *G* is the galvanometer. An auxiliary direct current source, consisting of a well insulated storage battery of about 20 volts, runs the sidebranch arc, so as to keep the cathode constantly active. It is probable that the arrangement is not as sensitive as a telephonic

receiver. It has, however, the advantage that telegrams can be registered.

SLOWLY MOVING CATHODE RAYS AND UNILATERAL CONDUCTIVITY

(a) *Starting of the Arc.*—The experiments described in the paragraph on the starting of the mercury arc by means of an auxiliary arc may be explained by the assumption that rays similar to the cathode rays of a Crookes tube are emitted from the cathode and propagate through the space with a velocity which depends on the amount of foreign gases or mercury vapor present in the space. If the vacuum in the tube is very

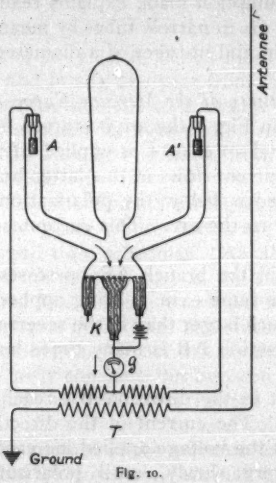


Fig. 10.

high these cathode rays move very rapidly and when they reach the anode a conducting bridge is established between the cathode and the anode. When the vacuum is poor, or when a great amount of mercury vapor is present, the speed of the cathode rays is reduced considerably, and through collision with the inert molecules and the recombination of the ions to neutral particles, a conditon can be established such that starting of the arc is very slow or even impossible.

Besides this influence of the amount of gas present the assumption of cathode rays emitted by the cathode at the low

voltage under consideration is also supported by the fact that the shape of the tube has a great influence on the starting of the arc. The starting takes place most readily when the anode is placed in a straight line with the cathode. If, on the contrary, the tube is of such a shape that cathode rays would have to change their direction a number of times before reaching the anode the starting becomes difficult. This is especially true when the cathode rays which are supposed to emanate from the surface of the mercury cathode have to impinge on glass walls or walls of similar material before reaching the anode.

Finally, the assumption made explains readily the fact that the starting of the arc in narrow tubes by means of an auxiliary arc is very difficult, and in tubes of a diameter below $\frac{1}{8}''$ practically impossible.

(b) *The Conductivity of the Mercury Vapor Diffusing from a Mercury Arc.*—If in Fig. 1 the arc is started between the electrodes C and B and an e. m. f. is applied to the electrodes B and A, a certain current flows in this latter branch, even when the e. m. f. applied is below the polarization voltage which would correspond to the arc. This current has the following properties:

1. The space in the branch AB possesses unilateral conductivity; i. e., the same e. m. f. being applied, the current in one direction is much larger than in the reverse direction. The current in the direction AB is many times larger than in the direction BA.

2. The current in the direction BA reaches saturation at very low voltage. The current in the direction AB first increases rapidly, as the voltage applied increases from zero on, then increases very slowly, until polarization voltage is reached, at which point there is a sudden transformation into an arc.

3. The current in the direction AB does not only depend on the e. m. f. applied and on the current in the arc CB, but also on the previous history of the branch AB. The current corresponding to the same e. m. f. is different when the e. m. f. is ascending and when it is descending.

The experimental data obtained and the theoretical deductions from them would take too much space and I intend to discuss them in the future in a separate publication.

(*Read at the Stated Meeting, held Thursday, May 17, 1906.*)

The Value and Design of Water Power Plants as Influenced by Load Factor.

By Dr. Frederic A. C. Perrine.

The load curve of any electric plant varies from hour to hour, from day to day and in any one year from month to month.

These variations are not due to a change in the number or character of the customers for light and power, but to the varying demands of the regular customers from daylight to dark and from season to season.

In any winter day the demand for lighting begins with the needs of the early risers whose habits are fixed by factory whistles and railroad train schedules. At about 6 o'clock the demand becomes the greatest and as the sun begins to show some light the load falls. From 7 to 8 o'clock the load begins to rise again as motors in factories and stores are started when the day's work has begun. From this period until about noon the load remains fairly constant, but between 12 and 1 mid-day the load falls rapidly and the lowest period of the whole 24 hours it reached. At 1 o'clock the load comes on again suddenly to about the amount of the morning load. As the afternoon advances and windows are darkened by the failing light lamp after lamp is turned on at a slowly increasing rate until about 4 o'clock when the load begins to mount rapidly, reaching its maximum at about 6 o'clock. At this time there are lights everywhere, in the office, the factory, the kitchen, the dining room, the living room and the bed room.

Within a few minutes more the load again begins to fall rapidly as the factory is closed and both lights and motors are discontinued. The offices are closed and the janitors have finished their work, the younger children are in bed and the elders have completed dressing and gone to dinner. A dip in the load

is then noted; but it increases again to a considerable extent when the theatres open; after they close a rapid fall is perceptible to a minimum which is reached between 1 and 2 o'clock, after which time only the all-night factories and lighting furnish the remaining load

If readings from the electric measuring instruments have been taken at hourly periods during the day and a curve drawn showing the load on a scale of hours this curve so obtained would be called the "load curve" for that day. The load curve for each day has its distinguishing characteristics. In summer the load would not show a rise in the early morning and in general will be decidedly less in amount during each period of the day, except during the daylight hours, when in any case the power load is the only load served; similarly as we move from month to month the characteristics of the load will change with the changing hours of daylight and work time. From day to day such a curve may be drawn and finally the yearly curve obtained. The term "the yearly load curve" has also been applied to a curve showing the daily volume of the *average* load throughout the year and also the term has been used to describe the curve showing the daily *maximum* load for each day of the year.

For the purpose of this discussion, however, we will confine the term "load curve," whether it be a daily or yearly curve, to the true value of the energy supplied per hour throughout this period.

In a study of the problem before us it is necessary to examine this load curve and describe some of its characteristics. First, we notice that the area of any such a curve represents the total number of kilowatt hours supplied to the load.

Second, that the average load is obtained by dividing the total kilowatt hours by the number of hours, and that having drawn a line across the curve at the height of the average load we see by inspection the hourly variation from the mean load. Finally, we obtain directly from the curve the value of peak or maximum load and the value of the minimum load, as well as the time of day during which the load is a maximum, a minimum. and a mean. With these facts in hand many points in the correct design of any power station are readily determined. Such points are the proper subdivision of units, the value of

overload capacity in carrying the peak, and the value of load for carrying which the machinery should be operated at its maximum of efficiency.

If from our load curve we obtain the value of the maximum load and the average load, the relation of these two is called the "load factor." In other words the load factor is the relation of the load actually obtained to the load which would have been obtained had a load equivalent to the maximum at any one time been carried throughout the period.

As in the case of the load curve this term "load factor" also is applied by different engineers to different quantities.

Some apply the term as it has been already defined, which is actually the only meaning which is really justified by the name "load factor."

But others claim that it is more expressive of the conditions which control the economy of operation in the plant; if it be defined as the ratio of the average load actually supplied to the maximum capacity of the machinery in operation at any one time. This use of the term is based on the assumption that all machinery in the plant not put into operation at some time for carrying the load must be considered as in the station for the purpose of reserve and that the cost of operation is most largely dependant on the capacity of the machinery at any time in operation

A definition of the term more directly useful in addressing of the problem in this way would be that the load factor is the relation of the average load to the capacity of the machinery in hourly operation, since the maximum station capacity at any time in operation represents a cost of operation in excess of the actual. On the other hand the cost of operation at full load of the machinery which is in hourly operation represents very nearly the true cost of operation.

There are others again who define the "load faction" as the relation of the average load to the total capacity of the station on the ground that the most essential element of cost is the total installation cost.

This latter definition of load factor is always in mind when the value of a hydro-electric station is given flatly in dollars per kilowatt of machinery installed.

But the load curve and the load factor are ordinarily con-

trollable by the business management of any plant by choice of character of load. The various customers of any power plant have each a particular load curve which is controllable only within very narrow limits, but the character of loads vary so greatly that it is possible by choice of customers to control the station load factor. This choice of customers is made to an extent automatic by methods of charging which penalize the undesirable load and encourage that which is wanted.

In attempting to increase the value of a load factor much has been accomplished by supplanting a lighting load by a railroad load. On a little reflection one at once sees that when the factories and offices close the cars run full, and furthermore, the greatest railroad load is in the summer when the lighting is the least.

In the case of a large hydro-electric station these two classes of load represent but a single element in the problem. Factories and industries of many kinds must be supplied. Hence it is necessary to either carefully select the load to be carried in accordance with the character of the plant or else to adopt the character of the plant to the probable load curve or load factor obtainable.

To one who has given even an elementary consideration to the problem of coal economy in a steam plant, the effect of load factor is at once apparent. The guarantees which are made in the contracts for steam machinery, and which are met in the plant tests are not realized as a matter of daily operation, excepting in the case of large pumping plants and steamships. The reason for this is not that there is a trick performed in the tests or that the machinery deteriorates rapidly after original installation, but it is due to the effect of the load factor. Whenever the load factor is unity the full economy realized on the test is also obtained in operation when the management is careful. But when the load factor is less than unity periods are encountered when the load carried is not the most economical and, especially if there are periods when fires are banked, the coal consumption in proportion to the load is increased.

This matter is of such great importance that it is difficult with a load factor of 30% to reduce the coal consumption to less than five pounds per kilowatt hour even though the steam ap-

paratus at its most economical load will operate on less than two pounds per kilowatt hour

This matter of load factor often affects the hydro-electric plant more seriously than the steam plant, though it is more generally true that the adaptation of plan to load factor is more often controllable in the design of the hydro-electric plant than in the design of the steam plant.

When the exceptional case of a unity load factor is encountered and at the same time the stream flow is constant, the plant and load are perfectly adapted to each other. This condition is to be found in certain of the Niagara plants and nowhere else. There the water flow is constant and the load is that of electro-chemical industries whose load is closely controllable.

Where the load factor is less than unity and a stream providing no storage is furnishing the energy, energy is wasted whenever the load is less than the maximum capacity of the stream. On the other hand where sufficient storage may be provided, a load having a factor of less than unity may be served without waste of hydraulic energy. Providing water storage for a variable load is the most direct method in design for attacking this problem.

Certain plants may be designed where the head and storage are simultaneously obtainable, and it is often advisable to sacrifice other elements of design to solve the problem in this manner. For example, the simplicity of plant obtained by the use of a high head has in certain plants already built caused an oversight of the fact that a construction more closely adapted to the condition of loading might have been obtained by changing the location to one of lower head but more than equivalent storage and at a lower cost in proportion to the service to be rendered.

Storage sufficient to take care of a load factor of less than 60% is rarely obtainable in larger plants where the head is less than about one hundred feet for the reason that the quantity of water necessary to store becomes too great to be provided in the available storage basins.

A correlative solution of this problem of design is found in the selection of the load itself.

The problem of design then becomes a problem in determining rates and is one which concerns the engineer as directly as

the design of the power plant itself. No one except the engineer can determine the load factor the plant may economically handle, nor can anyone save the engineer point out to the customer the modifications most readily made in his individual load to enable him to obtain service at the least rate and so obtain for the power plant the desirable load curve. For steam plants this problem has been studied carefully and definite methods are agreed upon for obtaining the highest load factor and the flattest load curve, which is all there is of the problem when using steam, but in the hydro-electric plant the problem and the advisable load curve is different in each case and must be separately solved in each case. This correct solution adds greatly to the value of the plant.

After all has been done that is possible in obtaining the best possible storage and in selecting the most satisfactory customers, it is often the case that there remains a residuum in the problem which may be economically handled only by steam or gas auxiliaries. But a short time ago the presence in any hydro-electric system of steam or gas auxiliaries was considered a confession of weakness in the hydraulic system. Fortunately this false idea is fast losing ground and it is recognized that the best of engineering is shown by their use, and in consequence fine hydro-electric opportunities are being utilized which were previously neglected.

Streams of comparatively constant flow by the installation of steam or gas auxiliaries are enabled to supply heavier loads than would be otherwise possible, though perhaps the most important use is found for auxiliaries in cases where the normal stream flow is very materially reduced during short periods of the year, by reason of special conditions in the water-shed.

No hydro-electric plant should at the present time be studied without considering the use of auxiliary power. Oftentimes such a study will result in the rejection of auxiliaries altogether. Oftentimes the employment of auxiliaries will, by the conditions shown, obviously be postponed to a later date than that of the original installation of the hydro-electric plant. But again, when it becomes apparent that auxiliaries are useful, it is immediately necessary to decide on the type of auxiliary installation most closely adapted to the conditions of water supply and loading. In some cases it is advisable to supply the

constant load by steam or gas auxiliaries, which are installed in such a manner as to obtain the greatest possible economy of operation, and in such cases the variable load will be supplied from the hydraulic installation. In other cases, the reverse is true, and then the problem presented for choice of the auxiliary is determined by ascertaining the plant which can be installed for the lowest capital charge and fuel charge for the load which the auxiliary plant is to furnish. This in some cases results in the use of uneconomical steam machinery, and in other cases in the use of machinery of the highest grade.

From what has already been said, it is quite obvious that the load curve and load factor are both involved in determining the gross revenue from any hydro-electric plant. It is true that in many cases of plants which have been installed, the revenue is based upon an assumed load factor of unity and charge for current made on the basis of the maximum customer's demand. This method of charging requires a rate lower than might be obtained by a different method of charging, since only those customers who can control their load factor to a value close to unity can afford to enter into such contract, and it is only justifiable where no means can be provided for handling a variable load factor in the plant and where sufficient customers for utilizing all the power furnished by the plant can be obtained. In general, the effect of this crude method of charging reduces the possible earnings.

Where it is impossible to find customers whose load factor is high or adapted to the supply, the value of the plant is consequently and correspondingly reduced, since no matter what may be the method of charging, whether on the basis of a rate per K. W. hour or on the basis of the maximum demand, the rate must be figured out in accordance with the type of demand and there is no way of charging which is equivalent to an engineering solution on the problem, which enables the curve of the actual load to be equivalent to the possible supply from the plant itself. An unsuitable load is not necessarily one of a low load factor but is one in which the curve of the load is different from the possible curve of output. A uniform load is unsuitable for a variable stream, whereas a suitable load and in consequence a higher revenue might be obtained from the same

stream if a variable load could be obtained corresponding to the variations of the stream flow.

Where the engineering of both plant and load can make the two load curves correspond exactly, the greatest possible output in revenue can be obtained from the hydro-electric plant, whether this be done by steam or water auxiliaries or solely by the engineering of the business department, in order to make the two curves correspond.

The common method of evaluating a water power plant is to state its cost or value in terms of dollars per unit of capacity, as we say that a plant is worth $100, $200 or $300 per K.W. installed. This method of rating the value of a plant is only suitable where the supply possible from the plant is at a constant rate and the load factor of the customers load is unity.

It is in general very false to reckon the value of a plant upon any other basis than that of its output in kilowatt hours, which is the true method of reckoning cost and determining the relative value of water power and other sources for obtaining power.

It is true that a considerable proportion of the plants already installed are valued solely upon a basis of capacity and that they are charging their customers upon a maximum demand rate, but it is also true that in a number of these very cases an increase might be made in the revenue if a rate somewhat dependent upon the customers load curve were adopted. The maximum demand rate encourages no customer save the one whose load factor is nearly unity, and who, in consequence, may supply his needs from other sources of power upon the best competitive terms. When the problem is so considered we see that the maximum demand rate of charging is a low rate for charging and in consequence the valuation of a plant upon the basis of its capacity alone results in an undervaluation of a large proportion of hydro-electric opportunities. The reason that this is so is that this method of valuation takes no account of the possible load factor or of the cost of power in the particular territory supplied when generated in any other manner.

The true method of valuing a hydro-electric plant is dependent upon its competitive value in the territory, and this requires that it be done upon the basis of the total number of K.W.H., which may be generated and sold.

The competitor of a hydro-electric plant is a steam plant and this steam plant runs at an increasing cost per K.W. hour with a variable load, in consequence any hydro-electric plant capable of supplying a variable load can obtain from that load a higher revenue per K.W. hour supplied than is the equivalent of the minimum stream flow, and often higher than the capacity of the total station and where the load is adapted to the possible output from the plant a more valuable installation is obtained, even though the minimum of the stream flow may be much less than in a corresponding plant, where the minimum flow obtainable is greater, but the load is unsuited to a full use of the stream.

The true method of evaluating any plant, whether steam or electric is on the basis of the K.W. hours of output which is saleable, and in making this statement we should not by any means neglect the fact that a very considerable item in determining the value of a plant is necessarily based upon the intelligence of the management and of the engineer in establishing rates which will obtain a load adaptable to the possible supply. Following the lead of other stations which are operating profitably often results disastrously to hydro-electric installations, when these installations might have been made greatly profitable by a proper adjustment of the loading and charging.

It is much simpler to multiply the rate of greatest possible output by a round number of dollars, but this method gives no idea of what is the true value of the plant. To obtain a value worthy of notice it is necessary to obtain the possible load curve of the customers and from this determine the construction of the plant and its operating cost and then after a similar estimate has been made of the cost by steam or the best other competitive power, an evaluation may be made which is intelligible.

It is not reasonable to develop a hydro-electric station, when a steam or gas station could be built which would supply the same territory at a less amount of cost, but it is also unwise to condemn a hydro-electric development, because the cost per unit of capacity is high, when at the same time it can develop cheaper power than can be done in any other manner.

There is nothing new or revolutionary in these ideas, and they but state the common sense view of the problem, but at the same time the present day usage takes into account only capacity figures with oftentimes added absurdities about "second"

power and "short time" power and "night power," none of which can be marketed under the system of charging proposed.

A recognition of the true method of valuing such plants which is here described would at the same time result in correct figures and would point out to the management as well as to the engineer what must be done to increase its value to the greatest possible figure.

This would result in a true evaluation of the hydro-electric development and result in an increase of what is already a large and profitable industry.

TIN IN SOUTHERN NIGERIA.

During the early part of the season 1904-1905, the officers of the Survey, John Parkinson and H. L. Huddart, discovered deposits bearing tinstone while making a traverse of the Uwet district. In view of the commercial importance of tin, it was considered advisable to examine carefully the stream deposits of this district, in order to determine their richness in tinstone. The district examined lies between Awai-Iku, on the north, the Ekpri-Ibami, on the south, and along the route passing through Akwa-Ibami, Uyanga, Oyja-Ekankpa, Oyja-Nkorimba, and Ofunapa. The deposits met with along this route were panned and examined for valuable minerals, more particularly for tinstone. Eighty-seven concentrates were thus obtained, and, after preliminary examination, forwarded to the Imperial Institute for detailed investigation. Most of these concentrates consist principally of garnet, staurolite and ilmenite; monazite, cassiterite, columbite, rutile, tourmaline, zircon and hornblende are subsidiary constituents, while gold occurs occasionally in traces. Of this series of concentrates, only those from the Akwa-Ibami district are sufficiently rich in tinstone to be of importance from a commercial standpoint.

The impurities in the tinstone concentrates of Akwa-Ibami consist of columbite, garnet, ilmenite and tourmaline, with a small amount of quartz and occasionally magnetite. Quartz can be eliminated by washing; the other impurities, being magnetic, can be fairly completely separated by the electromagnetic methods. In this way, the tin-bearing deposits of Akwa-Ibami could be made to yield a product containing, as a rule, the equivalent of 75 per cent. of metallic tin.

The conclusions to be drawn from this investigation of the stream tin deposits of Southern Nigeria are by no means of a definite character. The best occurrences can only be described as poor, in comparison with the generality of alluvial tin deposits.—*Eng. and Min. Jour.*

Mechanical and Engineering Section.

(Stated Meeting, held Thursday, April 26th, 1906.)

High Pressure Steam Tests of an Injector.

By Strickland L. Kneass, C. E.

There are few devices connected with the operation of the locomotive that awaken so much interest, both from a practical, as well as a theoretical point of view, as the Injector. A knowledge of its action under different conditions of steam pressure, height of lift and water supply temperature, is useful to the locomotive builder and railroad mechanical engineeer, while the relation of its performance to the theoretical formulae for delivery is of interest to the student of thermodynamics. It is therefore pertinent to present the results of a series of experiments covering an unusually wide range of conditions, and indicate diagrammatically the performance with locomotive boiler pressures, as well as the limitations of the Injector in service.

The instrument that was tested is known as the Improved Self-acting Injector, Size No. 10½, and embodies certain features which render its study of value, and though the experiments are not exhaustive, yet they cover most of the practical applications; other features which may be classed as minor, are omitted in this paper.

A sectional view of this Injector in its simplest form is shown in Fig. 1. From the delivery tube c the other parts are proportioned, and the diameter is 10.5 m/m (0.41″) at the smallest part of the bore. The main or forcing steam jet which forces the water into the boiler is 13.34 m/m (0.53″) in diameter and the annular area of the lifting nozzle corresponds to a circular opening 8.13 m/m (0.32″). A special feature of the design is

the continuous acceleration of the water between the suction branch and the smallest diameter of the delivery tube; the primary movement is given by the partial vacuum due to the condensation of the lifting steam jet a^1; the second, by the impulse of the steam discharge from this nozzle. The third increment is due to the low pressure within the condensing chamber of the forcing combining tube bb, and the final impulse, which adds sufficient velocity to the combined jet of water and condensed steam to pass through the contracted area of the delivery tube c, is due to the impinging of the steam from the forcing steam nozzle a. The resultant high velocity is then reduced to that of the water in the boiler feed pipe, by

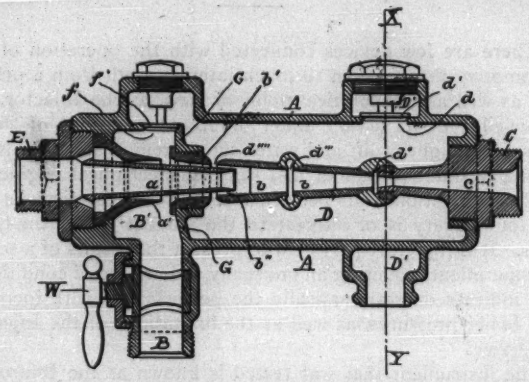


Fig. 1. Elementary form of Injector

the parabolic divergent flare of the delivery tube c, which is so proportioned that the negative acceleration or retardation shall be constant.

In this form of injector the two actuating steam jets are placed in the same axial line so that the combining tube of the lifting steam nozzle discharges its supply of water directly into the receiving end of the forcing combining tube. Owing to the peculiar design and proportions of the nozzles, the capacity of either set of tubes is much less than that of the combined apparatus; this is due to the fact that when the two sets of tubes are working in conjunction, the pressure within the

receiving end of the forcing combining tube is considerably below that of the atmosphere, and at times is 20" vacuum, increasing the flow through the lifting tubes. These conditions obtain as the steam pressure rises until the increased discharge of steam from the forcing nozzle requires a greater supply of water than can be obtained from the lifting tubes, so that while the forcing jet is passing the apertures d^{11}, d^{111}, which open into the overflow chamber D, a partial vacuum is produced in the overflow chamber; some of the water in the suction pipe B and water chamber B^1 will therefore be diverted from the entrance of the lifting combining tube b^1, raise the supplemental inlet valve f^1 and enter the overflow chamber D, submerging the openings of the forcing combining tube. The jet in this tube will then draw the supplemental water supply from the overflow chamber D into the combining tube bb and carry it through the delivery tube c, thus materially increasing the capacity of the injector.

At steam pressures below 120 pounds, the capacity of the lifting set is sufficient to supply the forcing tubes and the supplemental inlet valve f^1 is inactive.

The apertures d^{11}, d^{111}, and d^{1111} in the forcing combining tube bb have a further function, namely, that of free discharge of steam from both nozzles without producing a back pressure in the suction chamber D^1; this permits the Injector to restart automatically. Under all conditions of operation, there is a partial vacuum in the suction pipe, for the overflow valve d^1 and its connecting outlet passage are of ample size to permit the free out-flow of exhaust steam with all steam pressures.

The actual form of this injector, as used in service, is shown in Fig. 2, where No. 1 is the delivery tube, No. 2 the combining tube and No. 3 the steam nozzle; No. 42 is the supplemental inlet valve and No. 30 the overflow valve. The operation is as follows: Steam from the boiler is admitted to the lifting nozzle by drawing the starting lever No. 33 about one inch, without withdrawing the plug on the end of the spindle (7) from the central orifice which admits steam to the forcing nozzle No. 3. The discharge of steam from the lifting nozzle exhausts the air and condensed steam or hot water from the suction pipe. When water appears at the overflow, the starting lever No. 33 is drawn back and the injector delivers into the

boiler. At 200 pounds steam pressure about 20% of the total water supply for the tubes is admitted through the supplemental inlet valve No. 42.

The water regulating valve No. 40 is used only to adjust the capacity to suit the need of the boiler, as the automatic adjustment of the water supply to suit all variations of the pressure of the steam by the inter-action of the two steam jets prevents waste at the overflow valve.

During the operation of the Injector as described above, it is assumed that the temperature of the water supply is normal, but when it exceeds that with which the Injector will operate without wasting, the overflow valve No. 30 must be locked, and all subsequent overflow from the tubes will fill the overflow

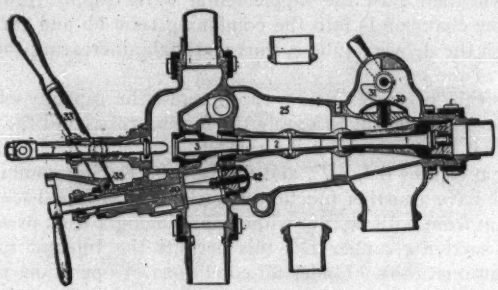


Fig. 2. Service form, lifting Injector

chamber and cause an external pressure upon the jet. The highest admissible temperature of the water supply will then be limited by the power of the jet of water when crossing the openings of the forcing combining tube, to withstand the lateral pressure of the contained fluids in the overflow chamber No. 25. The lower the velocity of the jet, the more sensitive it is to external pressure, so that if the openings at the widest part of the tube near the steam nozzle are protected, the jet can then withstand a higher pressure and the temperature of the water supply still further increased.

In the Class K (lifting or non-lifting) forms of this injector, the upper opening of the combining tube near the steam nozzle is protected by a special automatic valve No. 98, shown in

Fig. 3. This injector permits the use of a water supply reaching a temperature of 147° at 200 pounds steam, which is 22° higher than the limit of the form shown in Fig. 2.

The high pressure tests were made with steam taken from a 300 H. P. Babcock & Wilcox boiler, capable of carrying 300 pounds to the square inch; tests at the lower pressures were made with the same Injector and tubes, connected to a low pressure boiler in order to avoid superheating the steam by excessive throttling. A separator was placed in the steam

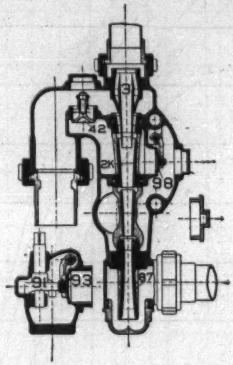


Fig. 3. Class K. Non-lifting form

pipe, lagged and carefully drained. The water in the supply tank between point levels, was weighed and continually rechecked; all thermometers and gauges were accurately calibrated; observations and readings were taken by three operators. As soon as a test was made, the result was plotted on a temporary diagram to determine its correspondence with previous operations; if found to vary from the general trend of the curves, it was repeated and errors thus eliminated as far as possible. In the final diagrams, the curved lines connect the individual observations and are extended above and below the limit of experiments according to the general tendency of the established curves. In each diagram the abcissas indicate the gauge steam pressures per square inch and the vertical ordinates, gallons per hour, degrees Fahrenheit, etc.

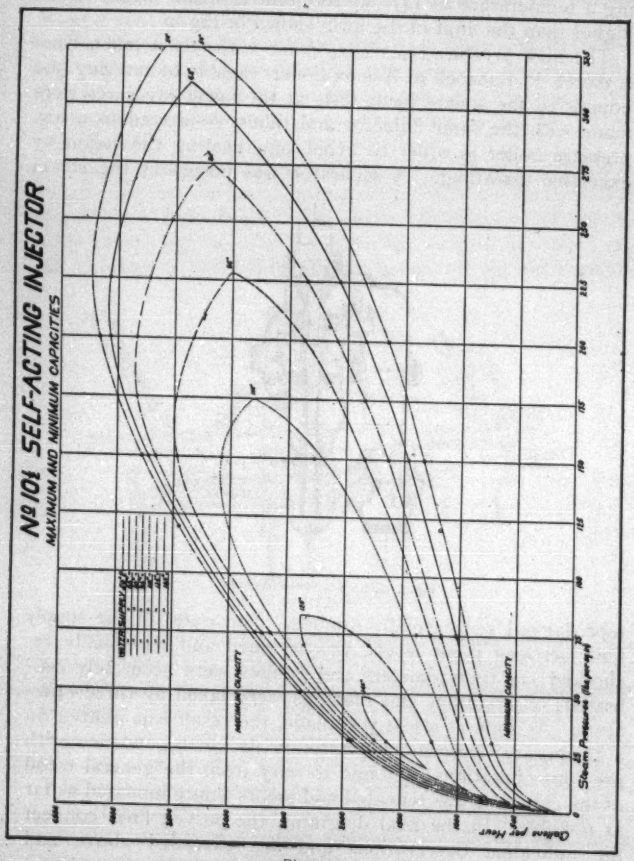

No 101 SELF-ACTING INJECTOR
MAXIMUM AND MINIMUM CAPACITIES
Gallons per Hour
Steam Pressure (lbs. per sq. in.)
MAXIMUM CAPACITY
MINIMUM CAPACITY
LIFTING
FORCING

Diagram 1

No 101 SELF-ACTING INJECTOR
LIMITING AND OVERFLOWING TEMPERATURES 25 INCHES LIFT
LIMITING TEMPERATURES GLASS 'A' MATRIX
LIMITING TEMPERATURES
OVERFLOWING TEMPERATURES
STEAM PRESSURES LBS PER SQ IN
DEGREES FAHRENHEIT

Diagram 2

The points on the curves at which the experiments occur are denoted by small circles.

Diagram I shows graphically the maximum and minimum capacity at steam pressures ranging from two pounds per square inch to 325 pounds, when the temperature of the water supply is 50°, 65°, 80°, 95°, 110°, 125° and 140°; the Injector in each case operating with the overflow valve free to open, to permit automatic re-starting. The vertical scale indicates gallons per hour from 0 to 4500, and the horizontal scale, steam pressures from 0 to 325 pounds.

From diagram I can also be obtained the range of capacities for any desired steam pressure and water supply temperatures, by subtracting the values given by the curved lines; for example, when the boiler pressure is 200 pounds, and the water supply 65°, the maximum capacity is 4,068 gallons per hour and the minimum 1,846, giving a range of 2,222. The overflowing temperature is that point at which no regulation of the water supply will prevent the emission of drops of water at the overflow; it therefore corresponds to the temperature at which the maximum and the minimum capacities coincide; this is indicated by the pointed junction of the maximum and minimum lines on the diagram for any given condition; for example, at 275 pounds boiler pressure, the overflowing temperature is 80°, at 175 pounds, 110°; points not shown on diagram may be interpolated, but are more clearly shown in diagram II, where the temperature tests are specially plotted.

The results shown on diagram I are of much interest and clearly show the remarkably high capacities given by this form of Injector at steam pressures varying from 175 to 250 pounds. The upward course of the line of maximum capacities corresponds closely to the theoretical line for perfect efficiency, based upon the well-known formula for efflux of water, $V = 2\sqrt{gh}$, the divergence being greatest at the high pressure. The tests were made with a single set of tubes for all pressures, operating as low as 2 pounds steam and tested as high as 250 pounds; the extensions of the capacity lines show the performance at still higher pressures.

Diagram II shows the limiting temperatures of the water supply. First, the overflowing, or maximum temperature of water with which the Injector can start automatically, and second, the

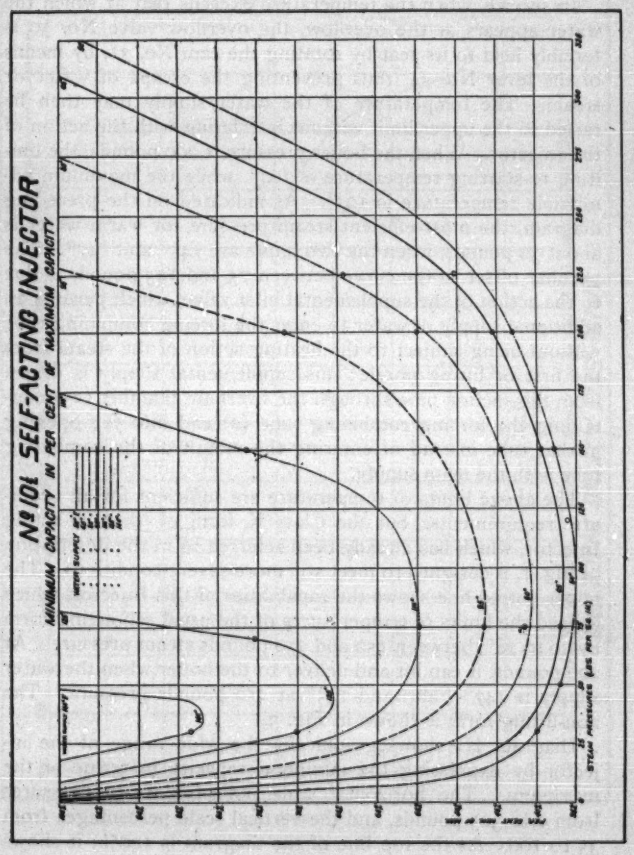

No 101 SELF-ACTING INJECTOR
MINIMUM CAPACITY IN PER CENT OF MAXIMUM CAPACITY
WATER SUPPLY
STEAM PRESSURE (LBS PER SQ IN)

Diagram 3

highest temperature of water supply with which the Injector can operate.

In service, when the temperature exceeds that at which the water appears at the overflow, the overflow valve No. 30 is forcibly held to its seat by rotating the cam No. 31, by means of the lever No. 34, thus preventing the escape of water or steam. The temperature of the water supply may then be raised to the upper limit without interfering with the action of the Injector. When the boiler pressure is 200 pounds, the limiting re-starting temperature is 104°, while the maximum admissible temperature is 125°. As indicated on the preceding diagram, the most efficient steam pressure for warm water is about 32 pounds, when the two limits are 145° and 147°. The peculiar offset to the curve between 75 and 125 pounds is due to the action of the supplemental inlet valve, which permits an additional supply of water to enter the forcing combining tube without being subject to the heating action of the steam from the first or lifting nozzle; this supplemental supply is drawn from the suction pipe through the overflow chamber (25) containing the forcing combining tube (2) and into the opening in that tube instead of entering the mouth of the combining tube with the main supply.

The above limits of temperature are sufficient for all ordinare requirements, but the Class K form of the self-acting Injector, which has already been referred to in the description of Fig. 1, is designed to meet still more severe conditions. The upper dotted line shows the capabilities of this Injector, which exceed the limits of temperatures of the usual self-acting form by 20 to 28°, between 150 and 250 pounds steam pressure. At 200 pounds, it can lift and deliver to the boiler when the water supply is 147° Fahr. and 135° at 250 pounds pressure. The non-lifting form is shown in Fig. 3.

Diagram III shows graphically the wide range of the injector by expressing the minimum capacity in terms of the maximum. The horizontal scale indicates steam pressures from 0 to 325 pounds, and the vertical scale percentages from 35 to 100. As the top line of the diagram is 100%, it shows the extreme limit of pressure for any given temperature of water supply and corresponds to the pointed intersection of diagram I, while a point on any curved line gives the definite

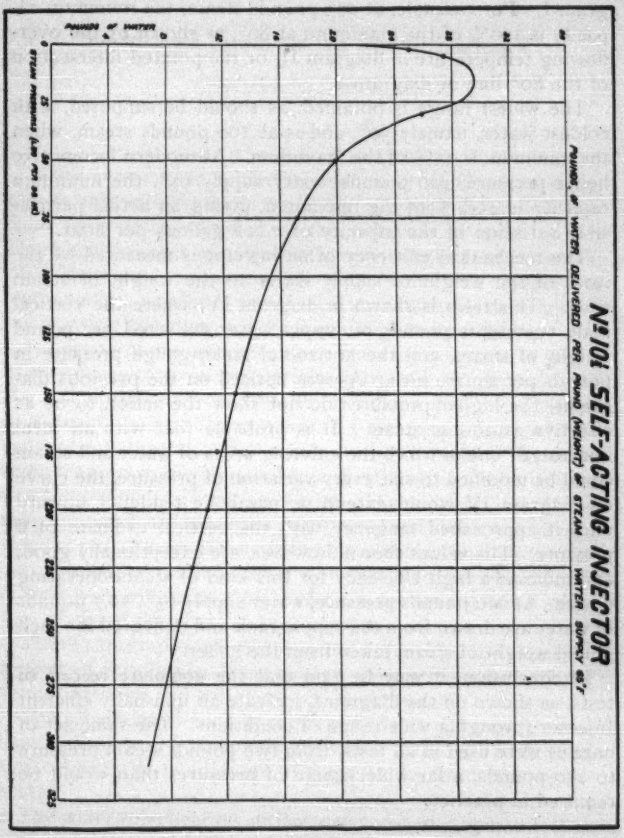

No 101 SELF-ACTING INJECTOR
POUNDS OF WATER DELIVERED PER POUND (WEIGHT) OF STEAM
WATER SUPPLY 65°F
POUNDS OF WATER
STEAM PRESSURE by GAUGE

Diagram 4

value of the relation between two points on any vertical line for the corresponding maximum and minimum lines of diagram I. For example, at 275 pounds steam, the minimum capacity is 100% of the maximum at 80°, as shown by the overflowing temperature in diagram II, or the pointed intersection of the 80° line of diagram I.

The widest range is obtained, as should be supposed, with coldest water, namely 50°, and is at 100 pounds steam, when the minimum is 35% of the maximum. At modern locomotive boiler pressure, 200 pounds, water supply 65°, the minimum capacity is $45\frac{3}{10}$% of the maximum, giving an actual permissible variation of the capacity of 2,222 gallons per hour.

The mechanical efficiency of an injector is measured by the ratio of the weight of supply water to the weight of steam used. This ratio is shown in diagram IV, where the vertical scale represents pounds of supply water delivered per pound weight of steam, and the horizontal scale, gauge pressure in pounds per square inch. As was noticed on the previous diagrams, the higher pressures do not show the action to be as effective as at low steam. It is probable that with an ideal injector, or one in which the entering areas of water and steam could be modified to suit every variation of pressure, the curve on diagram IV would extend its parabolic tendency upward until it approached tangency with the vertical ordinate of o pressure. The values shown, however, are exceptionally good, and indicate a high efficiency for this kind of steam-operating device. At 200 pounds pressure, water supply 65°, 10.7 pounds of water are drawn from the supply tank and delivered for each pound weight of steam taken from the boiler.

In conclusion, it may be said that the complete record of tests, as shown on the diagrams, indicate an unusually efficient Injector through a wide range of conditions. The same set of nozzles were used in all tests, from two pounds steam pressure to 250 pounds, a far wider range of pressures than would be required in practice.

Superheated Steam in the Power Station. *

By Arthur S. Mann.

Many questions in regard to the use of superheated steam can be answered mathematically by reference to some of the older laws usually applied to the behavior of water vapor. There are, however, questions of a very practical nature which, while they may or may not fall actually into the category of mathematical problems, are of vital importance in determining the practical advantages in the use of high temperatures.

A portion of any saving to come from the adoption of superheated steam for power generation purposes will depend upon the ease or difficulty encountered in making and in handling it in a steam station. Laws governing the generation and subsequent action of saturated steam are understood. There are some features in the action of superheated steam, however, for which there may be a perfectly plausible and scientific explanation, but which are in a sense unexpected and which can be urovided for in a practical way without a complete analytic explanation provided the facts are understood; the mere knowledge of such facts will make it possible to guard against error in design of steam chambers and piping systems.

These paragraphs will relate some of the experiences met in a plant of 8000 boiler horse power, generating steam of 185 pounds pressure and 200 degrees F. superheat.

The superheaters are a part of the boilers. There are three banks of tubes in a complete unit which make up the heating surface, and the middle one of these banks forms the superheater.

The water tube heating surface measures 4000 spuare feet in area and the superheating tube surface 1700 square feet. The stokers are of the underfeed type and the air supply comes to the fire under pressure.

*Read by title.

The furnace temperature is about 2400 degrees F., and the temperature of the furnace gases is about 900 degrees F. when they encounter the second or superheater bank of tubes.

With steady fires and with a boiler steaming at normal rating the superheat is very close to 200 degrees F. In one boiler trial having a feed temperature of 118 degrees F., the superheat was 205 degrees F., the boiler rating being 102 per cent., that is 2 per cent. in excess of normal capacity, and other trials have varied but slightly from these results.

The gases leaving the superheater bank have a temperature of 615 degrees F., and at the uptake this temperature has fallen to 445 degrees F. or 135 degrees below the temperature of the outgoing steam.

When one of these boilers was first started up it was felt that great care should be taken to avoid overheating the superheater tubes. Provision was made for flooding the surface exposed to the gases and the superheater was filled full of water and gradually drawn down until it was filled entirely with steam as the fires gained in temperature and steam was raised so that there was a flow through the tubes. It is well nigh impossible to injure superheater tubes when boilers are put in service in this way. There is a disadvantage, however, in that there may be a deposit of very dirty water in the superheater tubes and the ability to start in a simple way is to be desired.

It was found on trial that it was unnecessary to flood the superheater in starting new fires and that the tubes and joints would withstand any stresses put upon them provided the fire was started slowly, perhaps a little more slowly than would be considered safe practice with a regular saturated boiler. Starting with a dry superheater with slow fires has been proven to be safe practice and no trouble whatever has been experienced from this method.

The superheater tubes are heavy wrought-steel and are weldless. Very little trouble has been met in the care and management of the boiler and superheater. Some of the tubes have been re-rolled after the boiler was put in service; but in no case has a tube been re-rolled more than once and the boilers have been in use about two years. Not a single tube has been taken out or been injured in any way.

The degree of superheat is fairly uniform for moderate

changes in the amount of steam delivered. The hotter the fire, the hotter the gases about the superheater tubes; but at the same time more steam is passing through the superheater tubes and there is more substance to absorb heat. During a day's run the temperature will not vary more than 40 degrees, provided the feed water has a regular temperature. When the fires are cleaned, however, and there is no steam flowing through the superheater tubes, the steam that is there becomes hotter, averaging thirty degrees above the maximum of the day.

It is possible by forcing fires to increase the degree of superheat to 320 degrees F., giving a final temperature of 692 degrees, and even at this temperature there is no trouble with the superheater though the gases entering the superheater bank are well on to 1200 degrees in temperature.

It has been found that it is possible to have superheated steam and water in the same vessel. This is true even when every opportunity is given to steam to pick up the water and diminish its own superheat.

The superheater is made up of two horizontal drums about eight feet apart, one placed almost directly over the other with two-inch tubes extending from the lower to the upper. Steam enters the upper drum, makes two downward and two upward passes between the drums and leaves the upper drum to go to the steam system.

There is no deposit of water in the lower drum while the boiler is making steam. If, however, the boiler stops steaming and the fires are held in check long enough to allow the furnace gases to cool down, there is a deposit of water in the lower superheater drum. If this water is allowed to accumulate, there is a very considerable amount to be dealt with in the morning, 4″ or 5″ along the bottom of the drum perhaps.

When the fires are brought up again the outgoing steam is superheated in a very short time fully up to the regular average; but the water in the bottom drum is not absorbed by the hot steam sweeping over it. The surface of the water being some twenty square feet in area, the steam superheated on an average of 100 degrees passing over it at the rate of about 3′ per second, it would appear that this whole volume of water should be taken up and made into steam in less than thirty

minutes, particularly as the water itself is at the boiling point, or very near it. This water is not taken up by the steam however. It lies in the bottom of the drum until it is drawn out through a drain pipe.

Even though the rate of travel of the steam over the surface is slow, there is a decided tendency of the steam to pick this water up in slugs and carry it as water over to the steam pipe and into the steam ports and passages; and so far as it has been possible to observe, there is very little tendency to evaporate this water. It collects until there is an appreciable volume and then it is delivered in a body with the steam current.

As a consequence of this action, steam pipes, all low points and pockets in a system intended to convey superheated steam, must be drained as carefully as if the same system were to be used for saturated steam. It will not do to depend upon the supposed readiness of superheated steam to absorb water as it passes above the water surface.

It is not intended to give the idea that superheated steam will of itself deposit water as it travels through a pipe; but if the water is there it will not be absorbed gradually until it has all nicely disappeared. It is picked up in slugs and there is the same danger from water hammer that is met with in saturated steam pipe systems.

It would appear necessary to conclude that the fact that water is known to be present in a vessel does not preclude the possibility of there being superheated steam in contact with it.

The friction of superheated steam within a pipe appears to be greater than the friction of saturated steam. It has been found economical to give the steam high velocity because of the relatively low radiation loss and, though the actual drop in pressure is relatively larger, it may not be a mistake to submit to the loss of pressure from the boiler in order to avoid radiation losses from the pipe system. In the plant above described the velocity is about fifty feet per second through a system complicated by many elbows.

The question of pipe covering is a very important one, as the temperature difference, which is a factor contributing toward the loss in pipe radiation, is over 60% greater at regular loads and 90% greater at overloads, so that roughly there is 60% greater chance for loss than would be met under like condi-

tions with saturated steam. It has been found a money-saving plan to use covering 2″ thick on saturated steam work. After careful calculations had been made a thickness of 4½″ was chosen for the plant under consideration and when this covering was put on, great care was used to make good joints between covering sections, all possible leaks through covering and between covering and pipe walls being stopped up.

This thickness of covering was applied to pipe and flanges alike, the covering forming a compact body from end to end. The covering over the body of the pipe is finished with a canvas jacket; but this canvas is not carried over the flanges because of the fire risk.

In laying out a system of pipe particular attention must be given to provision for expansion of long lines. This is true of lines conveying saturated steam and more than ever true with steam at 580° F. The expansion is about double what it is in an ordinary pipe system, 3″ to every foot being the average for covered pipe and branches 100′ from an anchor point must be long enough to give 3″ safely if the main is put up cold and is cut to exact length.

It is not difficult to find a form of steam pipe joint which will be tight for superheated steam at these pressures and temperatures under discussion. It may not overstate the case to say that any good joint that would be adapted for saturated steam of equal pressure will hold superheated steam. The question of gaskets, however, must be considered carefully, and it is extremely easy to be deceived by the action of a gasket. Out of seven sorts of gaskets not one has been proven a failure during a three-months' trial. The real test of a gasket, however, is found in the number of times which it will successfully go through the operation of resisting the passage of water of condensation and whatever water may come from the lowering of pressure and drawing down the main and through stagnant steam in the pipe for a more or less extended period. What is really wanted as a packing that will always act in a pre-determined may under certain stated conditions.

Certain metal joints have served the purpose for over a year and there are joints in the station under discussion that have stood for two years, undergoing such changes in temperature a great many times. It frequently happens, however, that

a pipe joint adjacent to one of these joints which have stood so well, both provided with metal gaskets, will fail in three or four months and be unreliable in every way.

While the metal gasket is not to be condemned, the success of some of the sheet packings has been so marked that for general work they may be safely chosen. All of the more successful sorts have a great deal of asbestos in their make-up; in fact, there are four kinds of asbestos sheet packing in use at the station now and there is but one failure charged against these four. It seems safe to say, that if the joints face up fair and are provided with plenty of good stout bolts and the flanges themselves are heavy, that no great difficulty will be experienced in making sound joints.

The difficulties met in the handling of superheated steam are not severe, are not of a character that cannot be overcome, and the additional expense, over and above that met in a saturated steam plant, is very trivial.

A GROWING INDUSTRY.

The lapidaries of the United States are growing in skill, according to the statement of Mr. George F. Kunz, of the United States Geological Survey, in his report on the production of precious stones in 1905. No better lapidary work has ever been done at any period than in the last two years in this country.

The intricate Louis XV and Louis XVI designs in jewelry have been the fashion. Aquamarines, tourmalines, peridots, kunzites, and amethysts have been cut and polished not only in round designs but in oblong, hexagonal, octagonal, marquise, and pear-shaped forms. There has been especial preference for many of the larger stones. Never have aquamarines, tourmalines, and amethysts been sold in such profusion.

IMPORTATION OF CRYOLITE.

Considerable quantities of the mineral cryolite are imported from Greenland each year for use in the manufacture of sodium salts. The quantity of cryolite imported during the year 1905, according to a report made by Mr. Edmund Otis Hovey, of the United States Geological Survey, was 1600 long tons, valued at $22,482, as against 959 tons, valued at $13,708, in 1904, and 7708 tons, valued at $102,879, in 1903.

In the processes of manufacture calcium fluoride results as a by-product, and is saved to be sold for use as a flux in open-hearth steel furnaces in the same manner and with the same results as the natural calcium fluoride or fluorspar. The quantity of the artificial fluoride made depends, of course, upon the quantities of cryolite treated, and is said to be usually from 3000 to 4000 short tons per year.

Section of Physics and Chemistry.

(Stated Meeting, held Thursday, February 15th, 1906.)

Weather Forecasting From Synoptic Charts.

By Professor Alfred J. Henry.
U. S Weather Bureau, Washington, D.C.

Modern weather forecasting by synoptic charts is based on two well established facts, viz., (1), the general eastward drift of the atmosphere in temperate latitudes in the northern hemisphere, and (2), the close relation that subsists between the weather and the distribution of atmospheric pressure. These two facts are based on accurate observational data, and may be considered as the ground work of all scientific weather forecasting.

For the preparation of a synoptic chart two things are necessary, first, simultaneous meteorological observations over as large an area as possible, and, second, immediate collection of the observations at some central point.

In this country simultaneous meteorological observations are made twice daily and immediately telegraphed to Washington. To these are added by comity of exchange similar observations made in the Dominion of Canada. The total area represented in the field of observation is not far from 4,000,000 square miles, or about one-fiftieth of the area of the globe. This area is less than one-half of the land surface that can be controlled by the Russian Empire, in whose realms are found one-seventh of the total land area of the globe. This fact is pointed out merely to correct the impression that the natural opportunities for the development of a weather service on this continent are unsurpassed.

The Observations.—The following-named elements are observed: (1), the air pressure, (2), the air temperature, including the highest and lowest readings of the thermometer in the

twelve hours preceding the observation, (3), the direction and force of the wind, including the maximum velocity of the wind since the last observation, (4), the state of the weather and the sky, that is to say whether it is fair, raining, snowing, or sleeting, and whether the sky is clear, partly cloudy, or cloudy, and whether fog or haze is present. If clouds are present the kind and direction of motion are recorded. The amount of precipitation is also recorded, and the dew-point and relative humidity are determined. The full observation made at Washington, D. C., on the morning of February 15, 1906, is here given:

Barometer, reduced to sea level	30.29"
Temperature of the air: dry thermometer	19°
wet thermometer	17°
Max. (last 12 hours)	46°
Min. " "	18.8°
Wind: direction, northwest, and velocity in miles	20
max. velocity in last 12 hours, and direction N.W.	31
Rain in last 12 hours	Trace.
" 24 "	Trace.
State of weather	Clear.
Clouds, in tenths	1
kind,	Alto-stratus.
direction from	West
Relative humidity	69%

Since the height of the barometer varies with altitude and temperature the barometric readings are reduced to sea level and a uniform temperature of 32°, in order that they may be comparable *inter se*. A small correction is also applied to reduce the barometric readings to standard gravity. The next step in the preparation of a synoptic chart requires that the observations be telegraphed to a central point. For obvious reasons it is not practicable to forward the observations over the telegraph wires in full, as given above. Recourse to cipher codes is therefore necessary. The code now used by the United States Weather Bureau was devised by General A. W. Greely, the last of the military chiefs of the weather service. The code takes cognizance of even numbers only; for this reason the weather reports on all maps and bulletins always appear in even numbers. The code is a simple arrangement of consonants and vowels of the alphabet in a series of words so as to be readily translatable at sight. Thus the word "Dundee," according to

its position in the report, may mean, barometer 30.20 inches, temperature 24°, or a northwest wind with clear weather and maximum temperature of 24°. The significant combination of letters in the word are, Du=20; de=24. The values from 10 to 90 are obtained by the use of consonants; b=10; d=20; f=30; g=40; m=50; n=60; r=70; s=80; t=90. The unit figures are supplied by the vowels: a=2; e=4; i=6; o=8; u or y=0. Enciphering the observation by General Greely's code the observation takes the following form: Washington—doughboy—hyky—sumner—dubois—pitfall. The particular advantage of this code is found in the rapidity with which it can be deciphered and the economy in telegraph tolls that results from its use.

Collecting the Observations.—After the observations are enciphered the cipher report is immediately filed at the local telegraph office for transmittal to Washington. In order to expedite the transmission of weather reports to Washington absolute control is secured for about an hour and a-half of a number of trunk wires radiating in different directions from Washington as a center. A brief description of the method of sending and receiving reports over one of these trunk lines will suffice to illustrate the general plan of collecting and distributing weather reports. It should be remembered that the larger local offices of the Weather Bureau outside of Washington, D. C., must be supplied with daily reports for local use.

The Portland, Me., trunk line, so-called because its northern terminal is in that city, passes through the cities of Boston, Providence, Hartford, New Haven, New York, Philadelphia, Baltimore, and terminates in Washigton, D. C. At 8 o'clock each morning the weather report of the Portland station is sent over this wire and is copied, not only in Washington, but also in all of the other above-named cities. As soon as the Portland operator has finished sending his report, the Boston operator follows with his report, and in like manner each operator on the line sends his own report and copies those sent by the other operators. When the local reports on the Portland wire have been received in Washington the telegraph operator at that point transfers them to other trunk wires in that office and receives in return reports that have been received from other portions of the country. These he sends over the Portland wire to the stations on that circuit, the complete receipt and transfer of

all reports usually being accomplished in an hour and a-half, depending on the condition of the weather and its effect on telegraphic communication.

Preparation of Synoptic Charts.—As the reports come over the wires they are translated and transcribed on a set of blank maps of the United States and outlying territory. One principal and three auxiliary charts are made. The entries on the principal chart are as follows: (1) the temperature; (2) the air pressure; (3) the direction and velocity of the wind; (4) the amount of precipitation; (5) the state of the weather.

The three auxiliary charts show, (1) the changes in air pressure that have occurred in twelve and twenty-four hours, also any marked rise or fall in pressure that has been observed within the two hours immediately preceding the observation; (2) the maximum and minimum temperatures for each twenty-four hours, the temperature at the hour of observation and the changes therefrom that have occurred in twelve and twenty-four hours, also the departure of the temperature at the time of observation from the seasonal average; (3) the amount, kind, and direction of clouds. Two classes of clouds are distinguished, viz., upper and lower.

Thus it will be perceived the weather conditions prevailing at the same moment of time at the various stations throughout the field of observation have been translated into numerical expressions and symbols, the latter forwarded to a central point and there spread upon blank maps. The next step is to draw lines of equal pressure and equal temperature, since by this means the eye quickly perceives the salient features of the chart and the changes that have taken place since the last observation. Figure I shows the weather map on the morning of December 24, 1904, with the barometer lines (isobars) drawn thereon. The figures entered on the left of the circle indicate the temperature, pressure, wind velocity, and precipitation in the order named, reading from top to bottom. The direction of the wind is shown by the arrow passing through the circle, the condition of the sky as to cloudiness is indicated by the amount of shading. If the sky is clear the circle is not shaded. If rain is falling at the time of observation that fact is indicated by the letter R inside of the circle; if snowing, by the letter S. The isobars join places having the same pressure and are drawn for every tenth

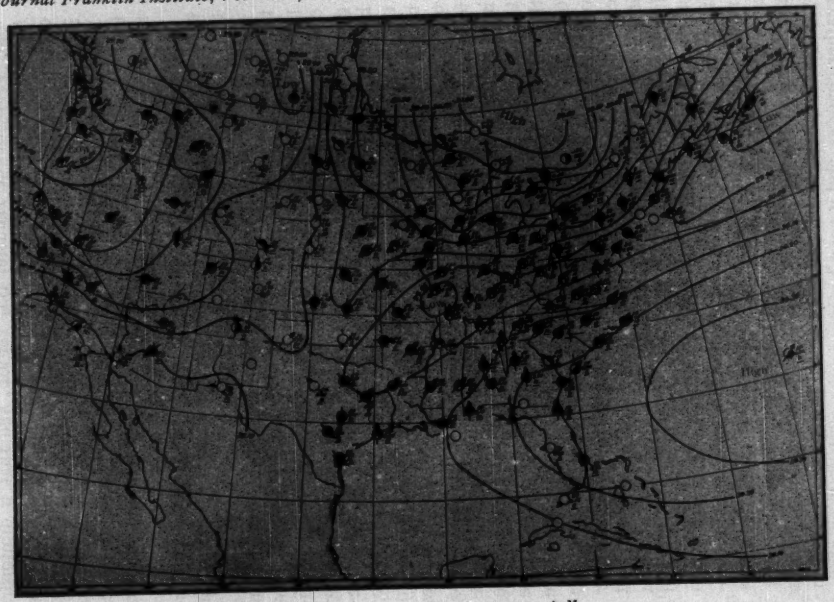


Fig. 1. Weather conditions December 24, 1904, A. M.

of an inch difference in pressure. Thus on the map above-mentioned it will be seen that pressure is high, 30.60 inches, immediately south of the Hudson Bay region, and that it diminishes thence to the Ohio Valley, where it is about 30.00 inches, increasing again toward Bermuda at which point it has risen to 30.36 inches.

In like manner places having the same temperature are joined by lines (isotherms). In the map under consideration the isotherms have been omitted for the sake of clearness.

The map is completed by marking the word "High" about the center of the region of highest pressure and the word "Low" in the center of the region of lowest pressure.

The Terms High Pressure and Low Pressure Defined.—The terms "high pressure," or "areas of high pressure," and "low pressure," or "areas of low pressure," have a special significance in modern weather forecasting. As was stated at the beginning of this paper the character of the weather is closely related to the distribution of atmospheric pressure; if, therefore, the distribution of atmospheric pressure on any certain day can be accurately foreseen a forecast of the weather would follow quite easily. Shortly after the barometer was invented it was found that rain fell more frequently with a falling than with a rising barometer, and that the probability of rain was greater when the barometer stood below 30 inches than when it stood above that figure. Instrument makers were prompt to take advantage of the facts thus observed and to mark opposite certain readings of the instrument the words fair, rain, changeable, etc. Whoever observes the barometer attentively will soon discover that it sometimes rains when the instrument stands at "fine" and that fair weather prevails at times when the glass indicates rain and storm. Since the making of synoptic weather charts was begun it has been possible to verify the belief of that celebrated burgomaster Otto von Guericke, of Magdeburg, viz., that there was evidently some connection between the weather and the rising and falling of the barometer. Synoptic charts gave at once a very greatly enlarged view of the natural processes involved in weather changes, and it soon became apparent that the weather at any point was almost wholly controlled by the eastward movement of areas of high pressure and areas of low pressure. It was also observed that the state of the weather at any point

depended more upon the position of these travelling areas of high pressure and low pressure with respect to each other than upon the actual reading of the barometer at that point. Thus it has been found that in the eastern part of the United States precipitation will begin with the barometer at 30.50 inches, provided the area of high pressure is to the northeastward of the area of low pressure. On the other hand precipitation seldom or never occurs in the eastern part of the United States, no matter what the barometer reading is, provided the area of high pressure is to the westward, say over the Ohio Valley, and the area of low pressure is passing off to sea along the Middle Atlantic Coast. The point of novelty in the modern method of weather prevision lies in the attempt to forecast the distribution of pressure that will prevail at the end of a specified period, say thirty-six to forty-eight hours in advance. If this can be done both the wind and the weather can be successfully forecast. The pressure distribution at any moment of time consists in a series of highs and lows encircling the globe with their maximum development in the temperate zones. For the purpose of this lecture it will be unnecessary to examine closely into their structure, suffice it to say that the wind circulation and the weather experienced in an area of high pressure is diametrically opposite to that which prevails in an area of low pressure. In general the chief characteristics of a high are (1) a central region of high pressure from which pressure diminishes in all directions; (2) clear skies with temperatures somewhat below the seasonal average; (3) light winds which blow clockwise around the periphery of the high. In short the high is indicative of clear, dry, cold weather. The low on the other hand is indicative of cloudy, moist, warm weather with strong shifting winds blowing contra-clockwise around the central region of lowest pressure. A clear understanding of the wind circulation around an area of low pressure and the general weather conditions that attend the passage of one of these atmospheric disturbances across the country is of very great importance. The diagram below, Figure 2, has been prepared to aid in the understanding of these phenomena.

The direction of the wind is shown by the small arrows in different parts of the diagram. These, it will be noticed, are disposed about the center of the storm (the inmost oval marked

"Low") in a rather orderly system. The wind does not blow directly toward the center, but rather spirally about it, as was discovered a little more than half a century ago. In the southeast quandrant the winds have a general southerly direction. In the northeast quandrant easterly winds prevail, while in the northwest and southwest quandrants the winds are mostly northwest to west. An observer stationed in lower Michigan at the point marked "A" will have fresh easterly winds, shifting as the storm center approaches him around to the south by

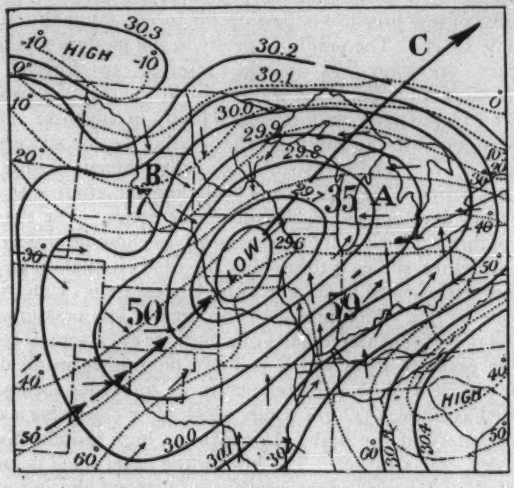


Fig. 2. A typical winter storm, showing wind circulation, isobars and isotherm.

way of southeast, and as the center passes him shifting still farther to the west or northwest.

This is what is meant by "shifting with the sun." On the other hand, an observer in South Dakota at the point marked "B" first experiences a wind from the North, and as the storm center approaches and passes him the wind backs to the west by way of northwest, and this is the meaning of the term "shifting against the sun, or backing." The weather experiences in the two locations, A and B, will differ as regards both temperature

and precipitation. At station A the temperature will rise, and it will continue high until after the center of the storm has moved, say to C. With the shift of the wind to the northwest the temperature will begin to fall, and the downward tendency will continue for twelve to twenty-four hours. The observer at station B will experience cold weather from the start, but the fall in temperature will not be quite so great as at station A. At station A the storm will begin with rain, turning to sleet and snow as the center passes and the wind shifts to a westerly quarter. At B the precipitation will be mostly in the form of snow.

If the diagram be divided into four equal parts by lines passing east and west and north and south through the word *low*, and the average temperature for each part or quadrant of the oval figure be calculated the result will be as follows: for the northwestern quadrant, 17°; for the southwestern, 50°; for the southeastern, 59°; and for the northwestern, 35°. The distribution of temperature is also shown by the dotted lines (isotherms). In the upper left-hand corner the temperature is 10 below zero (—10); between that line and the one next below, the temperature ranges from 10 below zero to zero, and so on until the lower left-hand corner is reached, where it will be noticed the temperature is 60° above zero. On the lower right-hand corner the temperature is only 40° above zero. So far as temperature is concerned, therefore, it is to be noted, that the right-hand* side of an area of low pressure is warm and the left cold.

The various steps leading up to the actual making of weather forecasts have now been sketched. It has been shown that the weather conditions prevailing at a given moment of time are carefully recorded and reported by telegraph to a central point; that they are there spread upon skeleton maps of the region in which the observations were made; that the areas of high and low pressure, respectively, are next located; and finally that it is the eastward movement of these shifting centers of high pressure and low pressure that controls to a great extent the weather experienced from day to day. It is evident, therefore, that the problem will be solved to a great extent whenever the course

*Note 1.—A person standing in the center of a storm, facing in the direction in which the storm is moving, will have the warm side on his right hand and the cold side on his left and in the rear.

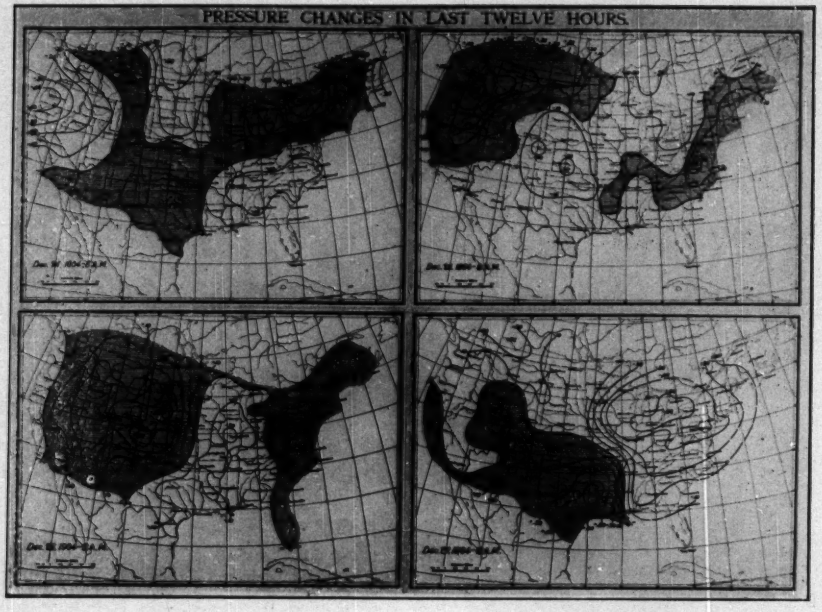


Fig. 3. The unshaded areas represent areas of falling pressure; the shaded areas rising pressure. The amount of rise or fall is given in hundredths of inches at the end of the lines.

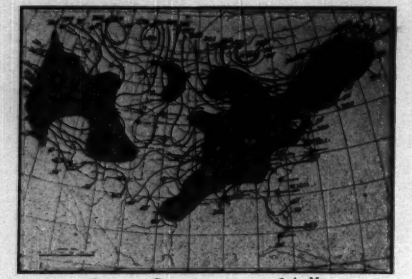
and rate of motion of the highs and lows can be accurately forecast.

Forecasting the Paths of Highs and Lows.—The importance of an accurate forecast of the path of a low to within at least one hundred miles is well illustrated in the case of storms approaching Lake Superior from the eastern Rocky Mountain slope. If, for example, the center of the storm passes northeastward over the western end of the lake the winds over the eastern end will set in from the southeast and vessels sailing westward will shape their course accordingly; if, however, the storm should pass northeastward over the northern end of Lake Michigan the winds over Lake Superior will set in from the northeast and drive vessels toward a rocky and dangerous coast.

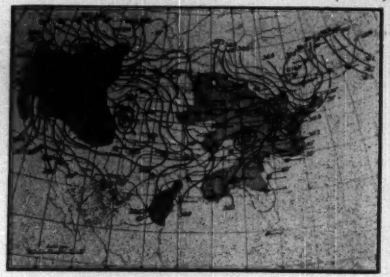
One of the results of many years observations has been to fix with a fair degree of accuracy the probable path of atmospheric disturbances wherever located. The knowledge thus gained is mainly useful in that it prevents the forecaster from assigning an impossible course to any particular storm. A knowledge of the most probable path of storms is also useful in cases where the influences which usually control their movement give negative results. It is then advisable to expect an increase in energy in the next twenty-four hours and to assign to the storm a normal course for the time and place.

The probable course of each high and the corresponding low or lows, for there may be more than one low, depending on or controlled by a single high, must be determined, not from average conditions, but by the actual conditions as portrayed by the maps in hand.

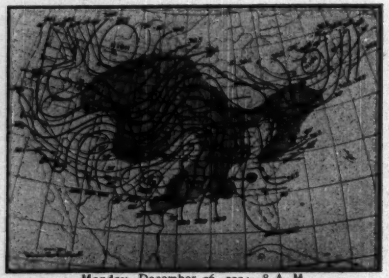
It is extremely difficult to convey a clear idea of the mental operations that are concerned in forming a conclusion as to the probable course of an atmospheric disturbance. In general the forecaster considers the form of the disturbance as shown by the general trend of the isobars, the direction in which they run, whether north-south or east-west. Attention is also given to the surrounding pressure distribution and especially to the changes that have occurred in pressure since the last observation. Some idea of the rapidity and extent of pressure changes may be had from the accompanying chart of twelve-hour pressure changes on four successive days in December, 1904. The rate of the eastward drift, whether fast or slow, the tendency of



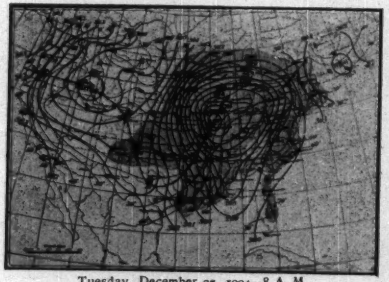
Saturday, December 24, 1904—8 A. M.



Sunday, December 25, 1904—8 A. M.



Monday, December 26, 1904—8 A. M.



Tuesday, December 27, 1904—8 A. M.

Fig. 4. Illustratng the movement of a North Pacific coast storm across the continent.

the centers of activity to shift from northern to southern circuits, the geographic position of the disturbance, the season, and indeed other details enter the problem.

In first approaching the subject of determining the paths of highs and lows the lay mind generally endeavors to reduce the seemingly endless confusion of pressure lines to a few simple typical forms; in some cases the endeavor is made to find similar maps in the belief that the various forms of pressure and temperature distribution repeat themselves in the course of time.

The method of finding similar maps may be dismissed with the remark that *no two weather maps are identical in all respects.* Occasionally two maps may be found with a number of points in common, but close examination will always reveal points of dissimilarity, especially in the antecedent conditions. The classification of weather maps according to geographic position and manner of origin is to be commended. In no other way will the student get a better appreciation of the almost numberless variations that are possible on any single type that he may select. One of the chief difficulties in the way of a working classification is the great number of sub-types into which any general type naturally falls. The usefulness of any system of classification diminishes directly as the number of sub-types increases, since in actual practice the forecaster is utterly unable to recall or recognize off hand the particular map or set of maps that the one in hand resembles. It is advisable, therefore, to limit the classification to a small number of general types and to forecast only the average conditions which are probable under the prevalence of any given type. In the United States the following working classification is suggested:

Working Classification of Storms in the United States According to Origin and Subsequent Movement.—(1) Northern boundary lows, first appearing, (a) in the North Pacific Coast States; (b) in Assiniboia.

There is a marked tendency in this group of storms to loop more and more to the southward as the cold season progresses and to pass out of the country by way of the lower lake region and St. Lawrence Valley. A very large proportion of the storms in the United States belong to this group.

(2) Middle Pacific Coast Lows; a relatively small group with a general southeastward movement across the Plateau and

Rocky Mountain region; thence northeastward to the St. Lawrence Valley.

(3) Arizona lows; most numerous in spring and fall months. These may be sub-divided into two groups, (a) those which move east-northeast to the lake region, and (b), those which take a due easterly course to the West Gulf Coast, thence northeastward to the St. Lawrence Valley via the Ohio Valley, or due eastward along the Gulf Coast passing off to sea over Florida.

(4) Eastern Rocky Mountain slope lows: a rather large group prominent in the colder months. These may be sub-divided according to the latitude. A considerable proportion of the storms comprising this group have their origin west of the Rocky Mountains, but first assume definite form over the eastern slope of the mountains.

This classification takes no account of storms originating in the Mississippi Valley, over the Gulf of Mexico, or south of Florida. It will be found, however, that fully 90 per cent. of the storms that appear in one portion or another of the United States have their origin west of the Mississippi River.

Inasmuch as it is not possible within the time at my disposal to even briefly outline the characteristics of storms which appear in the United States under the classification above given, a brief description will be given of a number of storms originating in or near the State of Kansas during the month of March in the years 1893-1902. The direction pursued by eleven of the storms, as also the rate of movement, is illustrated in the diagram below.

The various lines represent the total travel of each storm in thirty-six hours, the distance travelled in twelve hours being indicated in each case by an x in the line of total movement. From this it will be seen that, in general, the movement is east-northeast, and that the rate of motion is fairly uniform. Some of the most rapidly moving storms reached the Atlantic Coast and St. Lawrence Valley in thirty-six hours. Numbers 8, 9, 10, and 11 should be classed as erratics, that is to say either the direction pursued or the rate of motion was abnormal. Number 8 moved southeastward to Iowa, thence westward to Southeastern Nebraska, thence southward to Indian Territory. This abnormal movement illustrates an important phase of atmospheric changes in the spring months. At this time of year the great

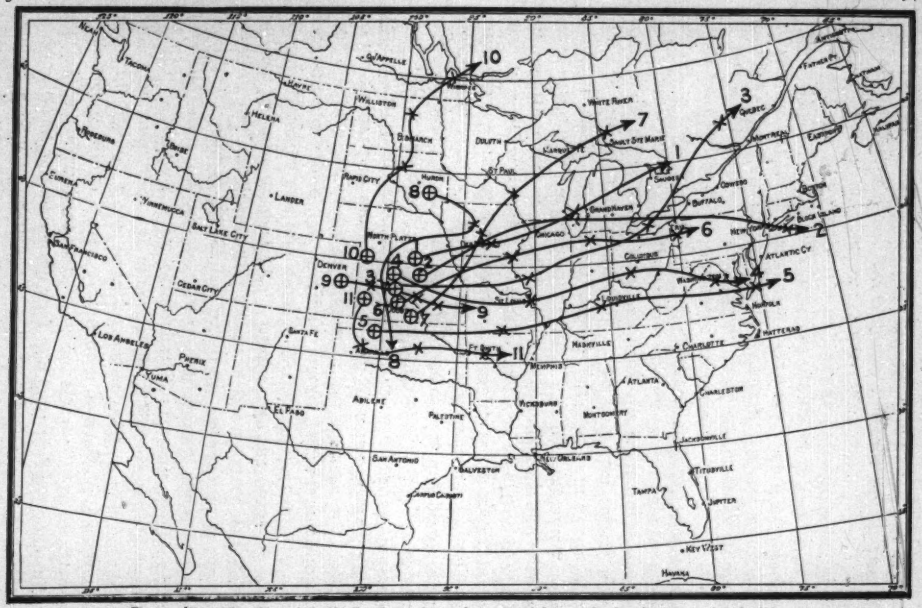


Fig. 5. Illustrating the variation in direction and rate of movement of storms having the same point of origin.

interior of the continent in the region of Hudson Bay is still ice-bound. Frequent incursions of cold air sweep thence southeastward into the St Lawrence Valley and New England, causing a marked fall in temperature over those regions. The increase in atmospheric pressure over the northern lake region that attends these incursions of cold air is strong enough to hold in check any depression that may appear west of the Mississippi River. If the depression is in the form of a long oval with its major axis east and west, the rise in pressure that spreads south and east from the Canadian border will fill up the eastern end of the depression and thus the central region of low pressure will *appear to have moved to the westward*. In this way the paths of areas of low pressure are occasionally given a westward movement on the maps of the Weather Bureau. There is still another way in which the center of an area of low pressure may appear to have moved to the westward, viz., by a fall in pressure advancing from a westerly quarter into an area of low pressure that may be stationary or slowly filling up. In this connection it should be stated that occasionally waves of falling pressure advance from west to east which are not sufficient in themselves to alter the contour of the isobars. These waves of falling pressure, or "surges," as they have been called by Abercromby, play an important part in the disintegration of the highs, and in some cases in altering the form of the lows. As just explained, a barometric surge may cause a secondary low to form to the westward of the original depression. The lows themselves, however, never move to the westward over the northern portion of the United States. In the Gulf and South Atlantic States in the hurricane season storms of this character may advance to the westward before recurving to the northeast.

The second erratic, viz., No. 9, occupied thirty-six hours in moving from Eastern Colorado to Eastern Kansas, whereas its normal movement in that time would have taken it to the lower Lake region. The slow movement in this, as in the preceding case, was due to a steady rise in pressure over the upper Lake region and in the direction of Hudson Bay.

The only storm of the group to move directly northward was No. 10. The movement of storms northward along the eastern slope of the Rocky Mountains is more pronounced in April than in March. This movement is caused, in part, by an increase in

pressure north of the Lake Superior region, supplemented by a rise in pressure over the middle California coast that advances eastward across the southern Plateau, thus forcing the depression that overlies the eastern slope of the Rocky Mountains to take a northerly course. As soon, however, as the pressure over the Lake region gives way, the storm will move eastward and down the St. Lawrence Valley.

From these concrete illustrations we may remark that failures in forecasting are due to several causes, chief of which are:

(1) Any sudden change in the rate of motion of either highs or lows.

(2) The movement of a high or low in an unexpected path or the sudden development of a low in a region where fair weather was expected.

(3) Errors in judgment of the forecaster.

(4) An important group of errors arises from the fact that even though the path of the storm be accurately forecast it is impossible to delimit with absolute precision the region over which precipitation will occur in its front, or continue in its rear.

Not very much is known of the exact processes which are concerned in the condensation of water vapor in the free air. While the evidence of the weather map points largely to the cooling due to direct contact of air masses of different temperature as the most efficient cause of precipitation, there are times when even this cause fails to produce an appreciable amount. Again rain may fall when the isobars and the general weather conditions give little, if any, indication of falling weather. Occasionally, too, a vigorous area of low pressure will pass along the northern boundary without causing any precipitation to speak of; in other cases precipitation of rain or snow will not begin until the Ohio Valley is reached, and then, without the usual preliminary clouding up to the westward. Judging from the evidence of the clouds condensation sometimes begins almost simultaneously over very considerable areas and then proceeds so rapidly that rain falls within a few hours; again the area of cloud may precede the fall of rain as much as twenty-four to thirty-six hours. The time which elapses between the clouding up of the sky and the fall of rain varies according to the form of the depression, but this subject has not been fully worked out.

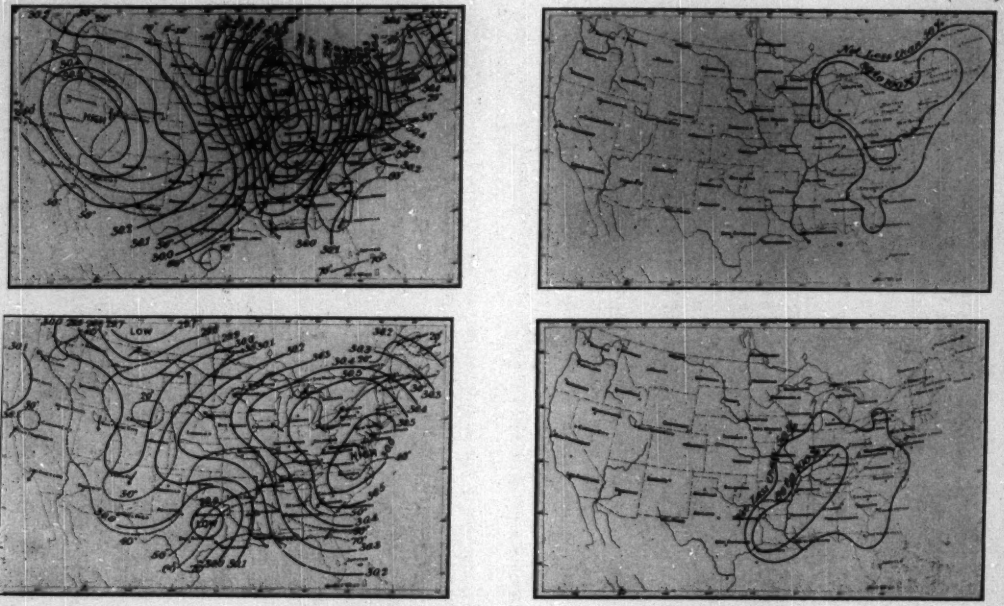


Fig. 6. Type maps and distribution of precipitation corresponding thereto.

Each forecaster must learn for himself the manner in which precipitation is distributed around areas of low pressure and on the front of highs in various parts of the country, and for the different seasons. The relation of the temperature to precipitation must also be carefully observed. In the winter months high temperatures are inimical to precipitation and accordingly the forecaster must withhold his prediction of rain until the center of the storm has passed and the cold westerly winds have set in. The distance that rain falls in advance of the storm center ranges from 1000 miles in extreme cases to less than 100 miles. In general the forecaster errs in placing the rain front too far in advance rather than not far enough. When the center of the low overlies the Middle Gulf Coast in the cold season and an area of high pressure lies to the northeastward with its crest over Nova Scotia, rain or snow is likely to extend to the southern New England Coast in twenty-four hours, other conditions being favorable. But should the area of high pressure be directly north of the center of the low, say over the Lake region instead of Nova Scotia, the northern limit of precipitation will not advance beyond southern Tennessee and North Carolina. In the last-named case the motión of both high and low is eastward and parallel and the line of no precipitation is sharply drawn in an east and west direction.

The chart below has been constructed to show for two different types of maps the area over which a forecast of precipitation would be successful in 80 to 100 per cent. of the cases, and where successful in only 50 to 80 per cent. of the cases. This chart fully confirms the previous statement that in the nature of the case it is not possible with our present knowledge of the subject to delimit the exact boundary of the region of precipitation; therefore there must always be a margin of greater or less extent surrounding the center of the rain area where the forecasts fail.

Notwithstanding the natural difficulties of the problem there has been a small gain in the accuracy of the forecasts in recent years, the period covered by the forecasts has been extended from eight to forty-eight hours, and instead of forecasts expressed in very general terms for large areas, definitive forecasts are now made for all of the larger towns and cities and for each of the states and territories regardless of its area. The most important gain in recent years, however, is in the adaptation of the

forecasts to the needs of special industries in various parts of the country, the perfection of the system of flood warnings and the general improvement in warnings of severe storms and cold waves.

SCANDINAVIAN WATER POWER.

The opinion has frequently been expressed that Scandinavia, with its huge waterfalls, will before very long be one of the most suitable places for large chemical works; indeed, it is claimed that with the future developments of electrochemical technology the greater part of the world's supply of soda, chlorates, nitrates, calcium chloride, and iron will be produced in the northern peninsula. Hence it is easy to understand the action of the Swedish and Norwegian Governments in protecting the falls against foreign capitalists. Sweden has passed a law that the use of the falls is reserved to the State, while a bill is before the Norwegian Storthing in which it is prescribed that at least one-half of the capital laid out on the falls shall be Norwegian money, and the direction of the work be in the hands of Norwegians who are living in the land.—*London Nature.*

STANDARD TEST FOR TRANSFORMERS AND TRANSFORMER IRON.

In a paper read before the Birmingham Section of the Institution of Electrical Engineers on April 25, Dr. D. K. Morris and Mr. G. A. Lister proposed a standard test for transformers and transformer iron. The method involves but one set of connections, three instruments, and the normal supply, and necessitates the use of two similar transformers. It is a modification of that first described in 1892 by Ayrton and Sumpner, and is an application of the Kapp-Hopkinson or differential method of testing direct-current machines. The behaviour of a transformer when loaded at various power factors is, they find, best considered by means of a regulation diagram which they have constructed. The short-circuit test can equally well be carried out with a transformer core excited. The three-point wattmeter method is probably the most accurate means of measuring power factor and current when carrying out single-phase tests on transformers or motors from a three-phase supply. By bringing the supply to the middle point in the testing transformer when carrying out the differential test, symmetrical conditions are obtained, thus permitting of a normal determination of the various losses. By varying the voltage only and taking wattmeter readings the core loss of a transformer may be separated into hysteresis and eddy-current loss by the method of the total index. Wattmeter readings in combination with the three-point method serve as the best means of measuring the temperature rise in heating tests. The method of constant induced voltage affords a ready means of finding the true hysteresis loss, and is probably the best way of testing iron samples.—*London Nature.*

Development of the Theory for the Kinetic Energy of Gases.

By Gustaf M. Westman,

1144 Broadway, New York City.

Heat is the reaction of work and is expressed by the difference in temperature involved ($T\text{-}T_0$) multiplied by heat capacity. The absolute temperature is the measure of the intensity of heat, while the heat capacity is the resistance of temperature.

Force is the motive power for work, and when n indicates the range of pressure in atmospheres per square meter $n^{\frac{k-1}{k}}$ is directly proportional to the absolute temperature, which, therefore, is the natural expression of force.

The attractive force begins at one atmosphere, and is, therefore $(n^{\frac{k-1}{k}} - 1)$ when the centrifugal force works below the atmosphere and is expressed $n^{\frac{2(k-1)}{k}}$, because two equal force are always at hand.

If n represents the range of pressure in atmospheres, determined by the product of the initial pressure and final volume, or the pressure at the beginning and the volume at the end of expansion, our principal energy formula is $n^{\frac{2(k-1)}{k}} (n^{\frac{k-1}{k}} - 1) \frac{c_v}{2} 546$, in which $n^{\frac{2(k-1)}{k}}$ is the two centrifugal forces; $(n^{\frac{k-1}{k}} - 1)$, the attractive force; $\frac{c_v}{2}$, the ratio of the molecular heat to the heat of expansion, and 546 the unit of energy in calories, derived from $\frac{22.3 \times 10630}{426}$ or the unit of pressure per square meter, multiplied by the number of cubic meters per molecule and divided by 426, the equivalent of heat in kilogrammeters.

A greater range of pressure than corresponds to the product of the initial pressure and final volume is always at hand, but the development of any range of pressure without increasing the volume does not create any work. It is necessary that both pressure and volume develop simultaneously in order to constitute a force.

In order to deduce this formula it must first be considered that a gas always consists of molecules and a gaseous matter around each molecule. If this gaseous medium for a moment is exposed to n-1 atmospheres' absolute pressure, a part is taken up by the gaseous medium, and the rest by the molecule.

Let us assume that in a given mass of any particular gas, such as oxygen, nitrogen, or steam, all the molecules are in rotation in a particular direction around parallel axes, and that the gas can expand only in a particular direction.

The effect of pressure on the molecule depends on the angle between the axis of rotation and the line of expansion, which we indicate by d. The greater the angle d, the less is the effect of pressure on the molecule, therefore this effect is marked cos d. The effect of the pressure on the gaseous medium is consequently 1-cos. d.

The pressure on the ether multiplied by the effect belonging to the ether, must be equal to the resistance of the molecule multiplied by the effect of pressure on the same, in order that the action and reaction shall be alike. If the resistance is marked R, the following equation expresses this:

$$(n-1)\,(1-\cos.\ d) = R.\cos.\ d\,;\quad n-1 = R\,\frac{\cos.\ d}{1-\cos.\ d}$$

The effect of the pressure is heat, and the ratio of the heat taken up by the molecule to that taken up by the ether stands in proportion as the molecular heat is to the heat of expansion, or $\frac{c_v}{2}$, which is equivalent to $\frac{\cos.\ d}{1-\cos.\ d.}$

If instead of the resistance R, we substitute the product of the forces belonging to the molecule, we will have the following formula, as all the free forces act simultaneously:

$$n-1 = n^{\frac{2(k-1)}{k}}\,(n^{\frac{k-1}{k}}-1)\,\frac{c_v}{2}.$$

Multiplying both sides of this equation by the unity of energy,

we arrive at the formula (n-1) 546 $= n^{\frac{2(k-1)}{k}} (n^{\frac{k-1}{k}} - 1) \times \frac{c_v}{2} \times 546$.

The formula for the kinetic energy of gases can be deduced from the above formula by observing that $n^{\frac{2(k-1)}{k}} = 4 (n^{\frac{k-1}{k}} - 1)$, which can be seen by substituting in the principal formula different values of n up to 27. Wherefore it can be written $4 (n^{\frac{k-1}{2k}} - 1)^2 \times \frac{c_v}{2} \times 546$.

We divide $\frac{k-1}{k}$ by 2, however, because when the kinetic energy develops, no change in volume of the molecule proper takes place, as the molecule expands adiabatically as much as it contracts by cooling in consequence of falling temperatures. Thus the formula will be:

$$4 (n^{\frac{k-1}{k}} - 1)^2 \times \frac{c_v}{2} \times 546.$$

The temperature necessary for the reaction must first be determined from which the kinetic energy can be calculated from absorbed heat and compared with the formula.

As can be readily understood, the higher the range of pressure is, the higher must be the initial temperature, in order that the kinetic energy may be expressed by the reduction in temperature.

It must also be remembered that heat alone cannot increase the kinetic energy, if the range of pressure is not increased at the same time, which can be understood from the fact that the heat is not the acting but the reacting force, just as in all chemical operations.

When the temperature of a gas is raised by adiabatic compression, the temperature of the kinetic energy is lowered, but not by the same amount for equal pressures, because the heat capacity must be counted as c_p at constant pressure by expansion, instead of c_v at constant volume by the compression.

In case c_v is the heat capacity during the expansion, the action of the gas would be perfectly reversible from one direction to the opposite; but it will be found by closer examination that

this is only a mathematical fiction. Not one such phenomenon as perfect reversibility exists, either of a chemical or a physical nature.

When the attractive force is used for compression, the centrifugal force acts during the expansion. It would be a peculiar coincidence if the square of a force in every instance would be equal to a linear force.

Besides, the heat capacity for air and steam is vacuum, which are both derived from c_p, shows conclusively that c_p is the true heat capacity during the expansion.

This change in heat capacity makes the fall of temperature for equal reduction of pressure caused by expansion of an ideal gas at $\frac{t}{1.41}$ of the temperature created by compression, depending, however, on the relation of the index of the kinetic energy in comparison with the index of the adiabatic compression, because the temperature is influenced not only by the heat capacity but also the heat quantity involved.

For instance, to compress a molecule of gas at 80° absolute temperature until the temperature is raised to 273°, it will take 68 atmospheres' pressure, whence the index of the adiabatic compression is $(3.4 - 1) = 2.4$.

On account of the heat capacity of expansion being different from that of compression, the adiabatic index must be altered to $1.41 \times 2.4 = 3.384$. On account of which it will take 91 atmospheres range of pressure from the beginning to lower that temperature to 80°, which can be seen from the following equation: $4(91^{\frac{0.22}{2}} - 1)^2 = 3.384$.

While by the adiabatic compression 256 atmospheres are needed to raise the temperature from 80° to 400° at an index of $(5 - 1) = 4$, the range of pressure needed for the kinetic energy to lower the temperature to 80° from 400°, will only be 220 atmospheres, because the index for the kinetic energy being $1.41 \times 4 = 5.64$, would amount to that figure, namely, $4\,(220^{\frac{0.22}{2}} - 1)^2 = 5.64$.

In the same way it is necessary to have respectively, 525, 740 and 1480 atmospheres' pressure to raise the temperature from 80° respectively to 493°, 546° and 667°, when only 364, 458 and

740 atmospheres, respectively, range of pressure are necessary for the kinetic energy to lower the temperatures from respectively 493°, 546° and 667° to 80°.

Herewith it will be shown that the kinetic energy stands in direct ratio to the reduced temperature from the initial temperature to 80°, the same as we have stated above. Wherefore we consider these temperatures necessary in order that the energies should correspond with our formula.

The reduced temperatures 193°, 320°, 413°, 466° and 586° multiplied by 23 give the following products: 4435, 7360, 9499 and 10,718, and 13,474 cal., when the kinetic energies for 91, 220, 364 and 458 range of pressure are respectively 4436, 7388, 9530, 10,750 and 13,570 cal.

For this reason we must consider 23 as the proper heat capacity of the molecule of air when expanding and rendering work, and 6.8 the heat capacity when the air expands against atmospheric pressure. This can be explained from the fact that volume and heat capacity are most intimately related to each other, so that the heat capacity for all bodies is altered by any change of volume. Heat is the reactive force on which the heat capacity and temperature depend, and the reactive force is proportional to the square of the volume, but in such a way that the heat capacity, under free expansion, is half the square of the heat capacity when expanding against atmospheric pressure. In other words, the square of the heat capacity is divided equally among the atoms of the molecule.

The development of the volume depends on the range of pressure, or the product of pressure and volume, which determines the kinetic energy, and if we give the gases enough temperature to be reduced, the kinetic energy will be equal to 23 multiplied by the reduced temperatures, or $Q = (T_1 - T_2) \times 23$ and our equation,

$$4\left(n^{\frac{k-1}{k}} - 1\right)^2 \times c_v \times 273 = (T_1 - T_2) \times 23.$$

in which T_1 is the absolute temperature at the beginning and T_2 at the end of expansion.

RELATION BETWEEN PRESSURE AND VOLUME.

The volume, as defined in thermodynamics, cannot show how the force acts, or how much energy is evolved, and in order to

do that we go to the vacuum or the developed volume, which together with the original pressure, will give us a basis for it.

Instead of the final volume, we use the term vacuum = v.

Instead of initial pressure = p, we use only the term pressure, and will define the pressure if otherwise intended.

As we consider vacuum to be an expression for volume and not for pressure, we will define it: The unit of vacuum for air consists of 0.5 volumes of absolute vacuum and 0.5 volume of air, and every additional unit has two volumes of absolute vacuum, each equal to the volume of the air, so that any magnitude of vacuum always contains 0.5 volume of air.

To determine the relation between vacuum and pressure we assume that $p^{0.71} = v$ for absolute vacuum, and as we have the range of pressure, or pv given, we can determine the vacuums and pressures, the product of which must be equal to the range of pressure.

p=pressure	14	23.5	31.5	36	47.7
v=vacuum	6.5	9.41	11.6	12.8	15.5
pv=range of pressure.....	91	220	365	458	470

If to the absolute vacuum is added 0.5 volume of air at its temperature in vacuum, we have the following values:

p=	13	22.2	30	34.7	46.7
v=	7	9.91	12.1	13.3	16
pv=	91	220	363	460	740
T_1=	273°	400°	393°	546°	667°

From the last figures we can find that $v^2 T = p^2 \times 80$.

$7^2 \times 273 = 13377$; $13^2 \times 80 = 13520$
$9.91^2 \times 400 = 39684$; $22.2^2 \times 80 = 39440$
$12.1^2 \times 493 = 72175$; $30^2 \times 80 = 72000$
$13.3^2 \times 546 = 96532$; $34.7^2 \times 80 = 96320$
$16^2 \times 667 = 170752$; $46^2 \times 80 = 170752$

From the last figures it can be seen that the square of the ratio of pressure to vacuum is equal to the ratio of the initial to the final temperature.

If we assume that vacuum is equal to the ratio of the initial to the final temperature multiplied by 2, we obtain the following values of vacuum: 6.82; 10; 12.3; 13.6, and 16.6, which favorably compare with the above, 7; 9.91; 12.1; 13.6, and 16, respectively.

We consider, therefore, this part of our theory a fully established, as the reduced temperature and heat capacity have been fully demonstrated.

We will now present another method of demonstrating the same thing.

DETERMINING THE KINETIC ENERGY BY THE PRODUCT OF THE FORCES.

When vacuum is arranged to correspond to the pressure, it can be concluded that the three natural forces work at their full capacity at the same magnitude, and that the amount of work is in proportion to the product of them.

One force is $n^{0.29}$, where n is the pressure in atmospheres, and consequently the product of the three forces is $n^{0.87}$. This product must be multiplied by the unit of energy per molecule, 546 cal., deduced from one atmosphere's pressure per molecule, divided by the equivalent of heat, $\frac{22.3 \times 10360}{426}$, after deducting the amount due to vacuum.

If the vacuum is 7 the unit of energy will be $546\ (1 - \frac{1}{7})$ cal. $= 468$ cal. per molecule.

In the same way for respectively 12.1; 13.3, and 16 vacuum, the unit will be 492; 500; 505, and 512 cal.

The forces for 13; 22.2; 30; 34.7, and 46.2 atmospheres' pressures are as follows:

$13^{0.87} = 9.31$,	which multiplied by	468	makes	4367	cal.
$22.^{0.87} = 14.8$	" "	492	"	7282	"
$30^{0.87} = 19.2$	" "	500	"	9610	"
$34.7^{0.87} = 21.9$	" "	505	"	11059	"
$46^{0.87} = 28$	" "	512	"	14336	"

From the fact that the heat capacity is constant during the expansion, it follows that $\frac{\cos. d}{1 - \cos. d}$, no matter how great d is, remains constant, and consequently the angle d must be constant. Therefore it can be concluded that the curve of expansion is a ligarithmic spiral.

Our formula for the kinetic energy is confirmed, not only by the temperature and heat capacity, but also by the product of the three forces.

Comparing the results of the three methods for determining the kinetic energy, we have the following results:

Range of Pressure.	Product of Forces.	Reactive Forces.	Principal Formula.
91	4367 Cal.	4435 Cal.	4436 Cal.
220	7282 "	7360 "	7288 "
363	9610 "	9499 "	9520 "
460	11059 "	10915 "	10750 "
740	14336 "	13478 "	13570 "

This table shows that our formula for the kinetic energy is correct for air when a vacuum corresponding to the pressure is available, and now we will see that the formula holds good under other conditions.

ENERGY DERIVED WHEN THE PRESSURE WORKS AGAINST ATMOSPHERE.

In the range of pressures the vacuum can be replaced by the product of temperature and pressure, making the final temperature 3.4 times greater, in which case we have only one volume per molecule to deal with, and then the heat capacity will be 6.8 cal. per molecule.

If, for instance, instead of 7 vacuum and 13 pressure, we make the pressure 91, it will give the former energy 4433 cal. by an initial temperature of 273° instead of 80°. In this case the reduced temperature must be $\frac{3.384}{1.41} = 2.4$. or $2.4 \times 273 = 655°$; whereas the energy is $655 \times 6.8 = 4454$ cal.

In the same way the following examples are calculated:

Atms. Pres.	Index for Kinetic Energy.	The Same Index / 1.41	Reduced Tem.
6	0.349	0.248	67°
9	0.584	0.42	112°
12	0.74	0.527	143°
16	0.96	0.68	185°

Pressure.	Energy from Reduced Temperature.	Energy from Formula.
6	$67 \times 6.8 = 456$ Cal.;	$0.346 \times 1310 = 457$ Cal.
9	$112 \times 6.8 = 761$ "	$0.584 \times$ " $= 765$ "
12	$143 \times 6.8 = 970$ "	$0.74 \times$ " $= 970$ "
16	$185 \times 6.8 = 1258$ "	$0.96 \times$ " $= 1257$ "

The vacuum can be diminished to any amount and replaced by pressure if the temperature is raised to corresponding

height, which, however, on account of the high temperature, can only be used for a small range of pressure.

According to the law of conservation of energy, and as a consequence of an adiabatic compression or expansion against the atmosphere, it follows that the product of pressure and volume divided by an absolute temperature remains constant in all stages of proceedings, or that $\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$.

As c_p is the true heat capacity during the expansion $p v^k$, will not be constant during the expansion as it is at the compression, in particular for air equal to 1.

This conclusion can be substantiated by the following table:

p	p_2	v_1	v_2	T_1	T_2
6	1.	0.28	1.42	456°	389°
7	1.	0.21	1.48	516°	404°
12	1.	0.1715	1.537	562°	419°
16	1.	0.14	1.86	611°	426°
91	1.	0.04	1.286	1010°	355°

From this follows that the formula for the second law cannot be used, as the law postulates that $p v^k$ must be constant in both cases.

Adherents to the second law claim, however, that c_v is the true heat capacity when the air expands against varying pressure. This illusion is taken away when the facts are considered that the kinetic energy and the energy of the adiabatic compression never have been found perfectly alike, which would be the consequence in this case.

(To be concluded.)

Franklin Institute.

(Proceedings of the stated meeting held Wednesday, September 19, 1906.)

HALL OF THE INSTITUTE,
Philadelphia, Sept. 19, 1906.

PRESIDENT JOHN BIRKINBINE, in the chair.

Present, twelve members.

Additions to membership since last report, fourteen.

The Actuary reported the death of Mr. Robt. C. H. Brock, a member

of the Board of Managers. The President, in referring to the circumstance, expressed the extreme regrets of the Board at the loss of one of its most active and valued members, and stated that the Board had already taken steps to name a committee to prepare a suitable memorial of its deceased member for publication in the *Journal*. The choice of a successor to Mr. Brock was, on motion, postponed until the annual election.

The President then introduced Prof. Lewis M. Haupt, who presented a communication on "The Relations of the Government to Our Waterways." The speaker's remarks were freely illustrated with the aid of lantern views.

At the close of Prof. Haupt's remarks, he offered the following preamble and resolutions, which were unanimously adopted:

WHEREAS, It is the present established policy of the General Government to provide ample facilities for the water-borne commerce of the United States and to emancipate inter-state commerce from the obstructions imposed by tolls or restricted canals under private or corporate control,

WHEREAS, This policy has been successfully inaugurated in all parts of the country with the exception of the early canals skirting the most populous and important cities of the Atlantic seaboard, and

WHEREAS, The best interests of the country demand the early construction of capacious canals connecting the interior waters of the bays and sounds of this coast, for commercial purposes as well as for national defense, and

WHEREAS, The most important and least expensive of these links is the one connecting the waters of the Chesapeake and Delaware Bays by a canal which is less than fourteen miles in length, and which has a trunk of only nine feet in depth and sixty-six feet minimum width, in which the Government is a joint owner, and concerning which its officials and commissions have invariably reported that it is vital for the protection of the coast, as has been demonstrated in our several wars, and

WHEREAS Congress has again authorized the appointment of a Commission to ascertain the expense of securing control of the works and franchises of the Chesapeake and Delaware Canal with a view to the acquisition of the aforesaid canal as a free and open waterway, which Commission is to report at the coming session of Congress.

Be it therefore *Resolved*, That the Franklin Institute of Pennsylvania reaffirms its position as to the urgent necessity of enlarging our coastwise waterways, and especially the Chesapeake and Delaware Canal for commercial and strategic purposes at the earliest practicable date.

Resolved, That a Committee be appointed to present this resolution to the Commission at the public hearing to be held in this city on the 27th inst.

The President, in accordance with the foregoing action, named Prof. Lewis M. Haupt, Dr. W. J. Williams and Dr. E. Goldsmith as members of the special committee to transmit the preamble and resolution to the Commission on the Chesapeake and Delaware Canal, which is to meet at the Philadelphia Bourse on Thursday, September 27th. Adjourned.

W. J. WILLIAMS, *Sec'y pro tem.*

JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

VOL. CLXII, NO. 5 81ST YEAR NOVEMBER, 1906

The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the *Journal.*

THE FRANKLIN INSTITUTE.

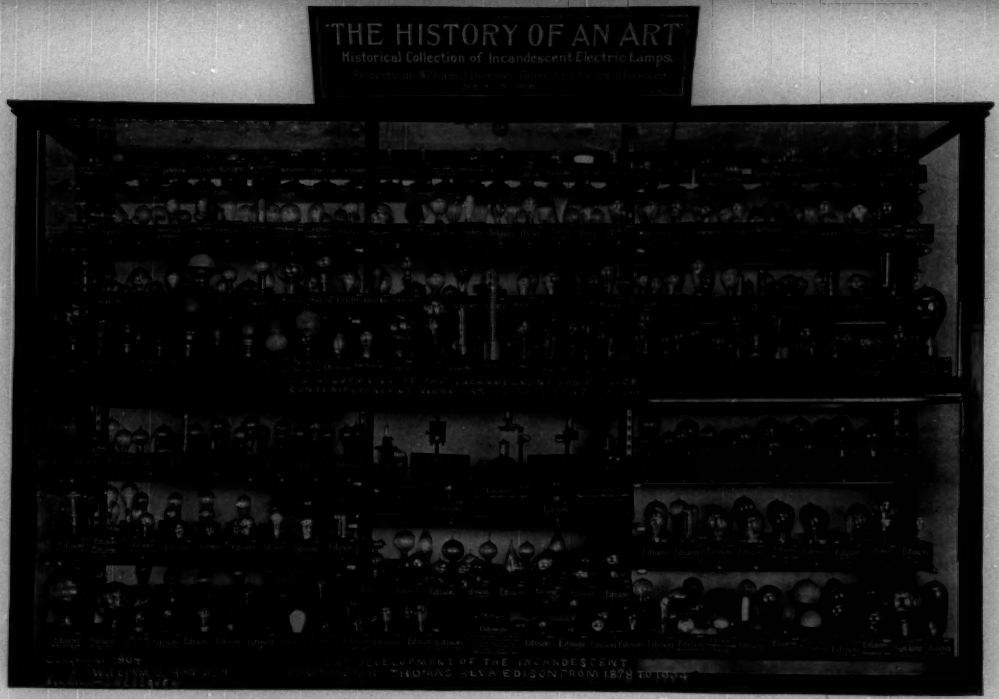
The William J. Hammer Collection of Incandescent Electric Lamps.

[*Being the Report of the Committee on Science and the Arts on the Historical Collection of Incandescent Electric Lamps made and Exhibited at the St. Louis Exposition of 1904, by Mr. William J. Hammer. Sub-Committee: C. J. Reed, Chairman; Carl Hering, Thomas Spencer.*]

[No. 2385.]

The Franklin Institute, acting through its Committee on Science and the Arts, investigating the merits of the collection of more than 1000 incandescent electric lamps, made by Mr. William J. Hammer, of New York, reports as follows:—

This collection of lamps, made during a period covering more than a quarter of a century, may truly be said to represent the "History of the Art." This history embodied in this collection is not a history that could have been recorded in words, that could be duplicated by any process or reproduced if destroyed.



History of an Art. William J. Hammer's Historical Collection of Incandescent Electric Lamps.